Processing morphologically complex words in native and non-native French

By

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Abstract

This dissertation investigates how individuals who learned French after childhood process inflected French verbs. Two experiments test the hypothesis that non-native speakers lack the grammatical representation responsible for processing inflection in the manner that native speakers are able to. Experiment 1 uses a masked priming lexical decision task to test if native and non-native French speakers are able to decompose inflected words into stem and affix, and access a morphological level of representation in the lexicon. Experiment 2 uses the same task as Experiment 1, but incorporates electroencephalography (EEG) to investigate the time-course of lexical access in native and non-native French speakers.

The results of both Experiment 1 and 2 indicate that non-native French speakers process inflectional information in a qualitatively similar way as native speakers. Additionally, the ability to process inflection in a native-like way is not restricted to learners at higher levels of proficiency; morphological processing is found across a wide range of proficiency levels. The results of the two experiments suggest that the grammatical representations and brain mechanisms responsible for processing inflection are available to adult second language learners, and may be available even in the early stages of acquisition.

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Chapter 1: Processing Morphologically Complex Words

Introduction

When acquiring a language, one must learn many components that make up the language. There must be a phonetic inventory of the sounds of the language, words to express meaning, a grammar to structure phrases, and mechanisms for interpreting sentences. With exception for biological impairment or abuse, the outcome of acquiring a language from infancy is a complete grammar and native proficiency. The outcome of acquiring a second language (L2) later in life, however, is highly variable. This dissertation investigates the limits of L2 attainment by focusing on a domain of language that is particularly difficult for adult learners: verbal inflection. Of particular interest is whether adult learners of a language are able to acquire a grammar that is sensitive to morphological structure of inflected words, and whether the non-native lexicon is structured with morphological units or unanalyzed whole-forms. The two studies reported here examine native and non-native processing of inflection in French, utilizing a combination of psycholinguistic and neurolinguistics methods, providing a unique window into whether learners are able to process inflection in a native-like way.

Overview of models of lexical processing

Over the past few decades, a tremendous number of studies have investigated the nature of the mental lexicon and how word recognition is achieved. Specifically, these studies aim to understand the units of representation that structure the lexicon. The current models of lexical processing fall into one of two opposing categories: *morphological* models, and *non-morphological* models. These two types of models differ in their claims about the structure of the lexicon, and differ in their predictions of how complex words (e.g., *walked*) are processed and accessed in lexicon. M*orphological* models posit that the lexicon contains morphological units of representation, and that when an individual is presented with a morphologically complex word the word is processed morphologically. Specifically, the complex word is believed to be decomposed into morphological constituents, and these morphological constituents are then activated in the lexicon. Within the category of *morphological* models there are further distinctions among models regarding the circumstances under which decomposition will take place. Some morphological models posit that morphological decomposition will always take place for complex words, and that a morphological unit will always be activated when an individual is presented with linguistic stimuli. Such models are often referred to as *single-mechanism* models because they predict a single processing routine that is responsible for processing all lexical items. Alternatively, other morphological models claim that the morphological processing route is used only under certain circumstances, and a second processing route is available when the morphological route is unavailable or dispreferred. Such models are often referred to as *dual-mechanism* models because they posit two distinct processing routes available to achieve lexical activation. In contrast to morphological models of lexical processing, *non-morphological* models do not posit that complex words are segmented into morphological constituents, and do not claim that the lexicon includes a morphological level of representation. Each of these model classes are described in greater detail below, but it is important to note the difference in claims between *morphological* and *non-morphological* models. The fundamental differences between these two opposing classes of models are the assumption of the basic unit of representation in the lexicon, and the type of processing operations carried out on complex words. Only *morphological* models assume that the basic unit of representation in the lexicon is the morpheme, and only *morphological* models assume that complex words are segmented into morphemes in order to activate the lexical entries of the constituent morphemes.

Morphological models of lexical access

Morphemes are the smallest unit of language that has semantic content. The words of a language can be a single free-standing morpheme (e.g., *cat*, *write*) that cannot be further broken down (i.e., the *ca*- part of *cat* does not have semantic content). The words of a language can also comprise multiple morphemes (e.g., *cats, writing*) where the internal structure of the word can be analyzed, and each morpheme contributes specific semantic content to the whole word (e.g., the bound morpheme –*s* in *cats* contributes the [+plural] semantic content; the bound morpheme –*ing* in *writing* contributes the [+progressive] semantic content). Bound morphemes (morphemes that cannot appear as single words, such as plural –*s*) can be categorized as either inflectional or derivational. Inflectional morphemes serve a grammatical function (e.g., tense and agreement; plurality, tense-marking), whereas derivational morphemes can either change the semantic content of the complex word (e.g., *write* → *rewrite*), or can change the syntactic category between the simple and complex words (e.g., *write* → *writeable*). Importantly, there are rules about how morphemes can combine in a language to build a morphologically complex word. These rules dictate what type of words certain morphemes can attach to (e.g., plural –*s* must attach to a noun; derivational *re*- must attach to a verb), but also the position in which morphemes can appear in relation to the stem. For example, in English all inflectional morphemes (like plural –*s*) and some derivational morphemes (like –*able*) must appear as suffixes at the end of the word, whereas other derivational morphemes like *re*- must appear as prefixes at the beginning of the word. In addition to knowing morphemes of a language, a speaker must also know the rules about how morphemes can concatenate to form complex words.

Morphological models of lexical processing take the approach that the lexicon is (at least partially) structured with morphemes, and that when an individual is presented with a morphologically complex word it is analyzed for morphological constituents which are then accessed in the lexicon and recombined to form an internally-structured representation for the complex word. Within the general category of morphological models of lexical processing there are two differing approaches to modeling lexical processing: single-mechanism and dual-mechanism.

Whereas *dual-mechanism* morphological models claim that some lexical properties lead to alternative whole-word processing routines (e.g., irregular morphology, high surface frequency, lack of semantic transparency), *single-mechanism* morphological models posit that all complex words are always processed according to their morphological constituents. Given that the main aim of this dissertation is to evaluate alternative models which disagree regarding whether L2 learners can ever use morphological representations, with particular debate on whether inflectional morphology is ever accessible to learners, the review of the literature on morphological approaches (below) focuses on studies aiming to adjudicate between morphological and non-morphological models. This review is largely focused on studies using the priming method, which is a powerful tool for investigating the early stages of lexical processing and adjudicating among various morphological models, and is also the method that is adopted throughout the experiments reported in this dissertation.

Single-mechanism morphological models

Single-mechanism morphological models posit that all complex forms are processed via morphological constituents. Such models predict that the lexicon is structured with morphemes, and lexical processing always involves access to a morphological level of representation in the lexicon. Evidence for such a processing mechanism has been found in a number of recent studies using magnetoencephalography (MEG), which has good temporal and spatial resolution to identify when and where a linguistic process happens in the brain.

Stockall & Marantz (2006) used MEG during two unmasked priming lexical decision tasks to test if English regular and irregular past tense forms are processed in a similar way. The unmasked priming lexical decision task involves the visual presentation of two words, the first word called the ‘prime’ and the second called the ‘target’. Both words are consciously perceived, and the participant’s task is to decide as quickly as possible if the target word is a real word in the language or not. This decision is made by pressing one of two designated buttons. The rationale behind such a task is that the relationship between the prime and target words will influence how quickly the participant is able to make the lexical decision. The experimental conditions can reflect various types of relationships (e.g., identity, morphological, orthographic, semantic) as a way of evaluating what type of relationship offers facilitation compared to an unrelated prime-target pair. In studies that incorporate other types of data, such as neurophysiological data, the relationship between prime and target can be examined to investigate if it modulates processing at the brain-level.

The stimuli in the two tasks were prime-target pairs that were either identical (e.g., *boil-boil*), orthographically related (e.g., *curt-cart*), or morphologically related. The morphologically related prime-target pairs were either regularly inflected forms (e.g., *jump-jumped*), irregularly formed with a high degree of orthographic overlap (e.g., *gave-give*), or irregularly formed with a low degree of orthographic overlap (e.g., *taught-teach*). The MEG component of interest in this study was the M350, which is believed to index stem activation in the lexicon[1]. In a priming context, the M350 typically peaks earlier when the prime is related to the target compared to when the prime is unrelated to the target (e.g., Pylkkänen et al., 2000). The MEG results of the two studies show equal M350 effects for targets primed by identity or morphologically related primes, with no difference of M350 effect between regularly and irregularly inflected forms. The authors took these results as evidence that regular and irregular inflected forms are processed in the same way, namely through a decomposition mechanism that activates the morphological stem in the lexicon.

Similarly, Fruchter et al. (2013) also used MEG to investigate English regular and irregular past tense using a masked-priming lexical decision task. Masked priming lexical decision tasks are similar to unmasked lexical decision tasks in that there are two words presented as a pair (a

[1] The M350 component is an MEG component that peaks around 350 ms after visual stimulus presentation. Numerous studies have found that the timing of the M350 component is the earliest MEG component modulated by lexical properties (e.g., frequency, repetition, semantic relatedness). Additionally, it is not modulated by properties associated with post-activation stages, such as phonological neighborhood density. Such findings suggest that the M350 corresponds with the timing of lexical root activation (see, e.g., Embick et al., 2001).

prime and target) followed by a lexical decision to the target word, but in masked priming tasks the prime word is presented too quickly for the participants to be consciously aware of (e.g., between 30 and 60 ms)[2]. Whereas Stockall & Marantz (2006) focused on the M350 component (believed to reflect lexical root activation), Fruchter et al. focused on the M170 component, which is believed to reflect the onset of morphological decompositional processes for visually presented stimuli (see e.g., Solomyak & Marantz, 2010). Similar to the findings in Stockall & Marantz (2006), the results of this study demonstrated equal priming effects for identity and morphologically related primes (regular and irregular inflected forms). The authors took these findings as further evidence that regularity of morphological structure does not influence the processing mechanism used to achieve lexical access. They concluded that all words are accessed via the same mechanism whereby a morphological unit is activated in the lexicon.

Another recent study by Crepaldi et al. (2010) used a masked priming lexical decision task to investigate if inflected words with irregular morphology (e.g., *fell*) would offer facilitation in recognition of their stem (e.g., *fall*). The stimuli in this study also accounted for the fact that many irregular past tense forms follow orthographic sub-regularities, and included morphologically unrelated words that follow the same patterns (e.g., *fell-fall¸ bell-ball*). The stimuli also included prime-target pairs that had the same degree of orthographic overlap as the morphologically related pairs, but were not related morphologically (e.g., *fill-fall*). The lexical decision reaction time data revealed that participants were significantly faster to identify the target word when primed by a morphologically related word compared to when primed by an unrelated word. Additionally, the priming from morphologically related words was significantly

[2] More detail about this type of task is provided below in the section titled "The masked priming method"

greater than any priming from orthographically related primes or primes that followed orthographic sub-regularities found in many past tense forms, indicating that the priming effect cannot be explained by rules applied to a subset of words. The authors concluded that the results of this study indicate that a single processing route is used to process all complex words.

Dual-mechanism morphological models

Perhaps the best known dual-mechanism model comes from Pinker's Words and Rules theory (1991, 1999). The Words and Rules theory focuses on the distinction of regular and irregular inflected words and posits that the distinction of these two types of words illustrates two components of language: rule-based grammar and memorized units that comprise the lexicon. Regularly inflected words are believed to be computed from stored morphemes by the combinatorial processes instantiated in the grammar. Irregular words are believed to be lexical entries that encode the past-tense in the lexical entry. The Words and Rules theory posits that when a lexical entry is available for an inflected form, the rule-based combinatorial route is blocked. In the event that a whole-form retrieval fails (due to lack of lexical entry), the rule is then applied to produce a regular form. Pinker argues that such a dual-mechanism approach to inflected words is a more powerful model than connectionist models of the lexicon such as Rumelhart & McClelland's (1986) pattern-associator model (called RMM) or generative phonology's rules for irregulars (Chomsky & Halle, 1968). Pinker argues that connectionist models such as Rumelhart's & McClelland's RMM are weakened in their predictive power because these models do not incorporate an explicit rule component. For example, whereas English speaking adults and children will very frequently inflect novel words with a form of *–ed* (e.g., Berko, 1958; Marcus et al., 1992; Vargha-Khadem, Watkins, Alcock, Fletcher, &

Passingham, 1995), RMM often produced strange inflected outputs for novel or untrained words (e.g., *membled* for *mail*). Pinker argues that a rule-based grammar is critical to modeling inflection, such as English past tense. Pinker additionally argues that the dual-mechanism approach of the Words and Rules theory is more suitable for modeling English past tense inflection compared to generative phonology models (e.g., Chomsky & Halle, 1968) which claim that irregular forms are generated by affixing a morpheme to a verb stem and applying phonological rules to change the phonology of the stem. While such rules may work well to model somewhat predictable irregulars (e.g., *ring-rang, sink-sank*), the exceptions to such rules would need to be extensive to avoid predicting forms such as *rin* being the underlying representation for *run*. In sum, the power of the Rules and Words theory comes from its ability to model a default rule-application route when a memorized alternative is not found in the lexicon, which closely resembles production data from adults and language-acquiring children.

Pinker's Words and Rules theory does not limit the memorized inflected words to just irregulars; regularly inflected words can be stored too. The theory is not meant to necessarily dichotomize words according to regularity. Instead it claims that any word can be stored in its whole-form, and accessed as such, but when no such lexicalized item is found in the lexicon (or the direct access route is not the fastest route) the rule-based, combinatorial route will be used.

Similar to Pinker's Words and Rules approach to understanding lexical processing, Ullman (2001, 2015) has proposed the Declarative/Procedural model which posits that two specific memory systems (declarative memory and procedural memory) subserve certain components of language processing. The incorporation of specific brain memory systems is the key distinction between Ullman's model and Pinker's model. Ullman's model is not exclusively aimed at describing lexical access (other linguistic domains such as syntax are described), but for the purposes of the present discussion only its claims regarding processing morphologically complex words will be presented. Ullman's model of processing is similar to Words and Rules in that it posits that some complex words will be processed through a rule-based mechanism (procedural memory), whereas other complex words will be processed via a storage mechanism (declarative memory). Ullman posits that these memory systems are not domain-specific (other cognitive functions are carried out via these systems), but they are used for a number of linguistic functions. The declarative memory system is believed to be responsible for memorizing facts and episodic information. Specific to language, Ullman considers this the memory system that subserves the mental lexicon which contains stored words. The procedural memory system, by contrast, is believed to be responsible for systematic processes. Specific to language, Ullman posits that this memory system is responsible for composing and decomposing regularly inflected words. Similar to other dual-mechanism models (like Pinker's Words and Rules) Ullman's Declarative/Procedural model posits a dichotomy where some words a processed via rule-governed mechanism that is sensitive to morphological structure, and a storage mechanism that contains idiosyncratic whole-forms such as irregularly inflected forms (e.g., *taught*).

Dual-mechanism models such as Words and Rules and the Declarative/Procedural model have considerable support from psycholinguistic and neurolinguistic studies. In a priming task with lexical decision during electroencephalography (EEG) recording, Münte et al. (1999) tested if English regular and irregular past tense forms showed similar processing patterns. Participants were visually presented with isolated target words for 300 ms each and made a lexical decision for each target. The stimuli lists included pairs of morphologically related words, spaced out over the presentation list (primed items), and also verb stems for which there was no morphologically related form included in the list (unprimed items). The morphologically related pairs were either regularly inflected (e.g., *walked-walk*) or irregularly inflected (e.g., *fought-fight*). Nonce targets were also included in the presentation lists. Previous EEG studies found that words repeated within a stimulus list elicited smaller N400 EEG component[3], indicating easier lexical access for words that had already been seen compared to words that were previously unseen (e.g., Nagy & Rugg, 1989). Münte et al. investigated if the repetition effect found in previous studies would be found for morphologically related words, and if regularity of the inflection influenced whether or not a priming effect was found. The results of their study showed that for regularly inflected items, the second item of a related pair elicited a reduced N400 component compared to items that had been presented only once in the presentation list. The results for the regularly inflected items were interpreted as evidence that the inflected form is decomposed into stem and affix, such that the stem is repeated across the appearances in the presentation list. The irregularly inflected forms, however, showed a different pattern. There was no reduction of the N400 for the second item of a pair with irregular inflection. The findings for the irregular items were interpreted as evidence that complex forms that are irregular in their inflection are not decomposed into stem and affix. Münte et al. interpreted the findings of their study as support for a dual-mechanism approach to lexical activation. They argued that morphologically complex words are decomposed and accessed according to their morphological constituents, but this processing path is only available for complex forms carrying regular morphology. When a

[3] EEG components and their significance are discussed in greater detail in Chapter 3. Briefly, the N400 is an EEG component believed to reflect lexical processing. Smaller amplitude reflects facilitation of lexical access.

complex form carries irregular morphology, the decomposition route is unavailable, and instead the whole-form is accessed in the lexicon.

Numerous studies using methods other than priming have found evidence in support of dual-mechanism models. Hahne et al. (2006) and Penke et al. (1997) used EEG recording during sentence processing and found that German regular and irregular inflections are processed differently. Specifically, they claimed that regularly inflected forms are processed via a rule-based mechanism, whereas irregularly inflected forms are processed as whole-forms. Alegre & Gordon (1999) found evidence of whole-word storage for regularly inflected English words of sufficiently high surface-frequency, but evidence of rule-based processing (decompositional) for regularly inflected words of low surface-frequency in an unprimed lexical decision task. Lehtonen et al. (2009) used functional Magnetic Resonance Imaging (fMRI) during a visual lexical decision task to compare the processing of inflected Finnish words to inflected Swedish words. Finnish has a very large inflectional paradigm whereas Swedish has a more limited inflectional paradigm. It was predicted that highly inflectional languages like Finnish would be more dependent on rule-based decomposition processing routes to process visually presented inflected forms compared to languages that have smaller inflectional paradigms. The results of the study showed greater brain activation in areas associated with morphological processing (the left inferior frontal gyrus (e.g., Vannest, Polk, & Lewis, 2005) in Finnish than in Swedish. Lehtonen et al. concluded that language-specific properties of the inflectional paradigm may influence the degree to which the rule-based decomposition processing route is used relative to the whole-word storage route.

Non-morphological models of lexical access

Non-morphological models of lexical activation posit that the morpheme is not a necessary construct to model lexical processing (e.g., Hay & Baayen, 2005). In fact, such models take the position that morphology is not a distinct feature of language, but is instead the convergence of shared form and meaning between related words. For example, in a *network* model of the lexicon such as Bybee's (1995), unstructured whole-forms (e.g., *walk, walked, walking*) are linked together in a network by virtue of their overlap of form (phonology and orthography) and overlap of meaning. The connections between two words in the network are strengthened by the degree of overlap of form and meaning. Similarly, *distributed connectionist* models (e.g., Seidenberg & Gonnerman, 2000) posit connections between units of representation that correspond to the form of a word (orthography and phonology) and the semantic meaning. Over time, as learning occurs, the connections between the form representations and semantic representations are strengthened for related words that are traditionally described as morphologically related. While the various non-morphological models vary in their assumptions about the unit of representation in the lexicon, such models are similar in their claim that discrete morphemes are *not* the unit of representation in the lexicon. Instead, the lexicon is believed to be a network of connections where individual representations are strengthened by shared form and meaning.

Gonnerman et al. (2007) used a series of cross-modal priming lexical decision tasks to test if the degree of semantic overlap between prime and target modulated the size of the priming effect. In a cross-modal task, participants typically hear the prime and see the target (thus, the task includes a cross of the auditory and visual modalities). In addition to the cross-modal priming tasks, Gonnerman et al. had a large group of native English speakers rate the semantic similarity between word pairs as a means of quantifying semantic relatedness for the cross-modal priming test items. The test items included prime-target pairs in three conditions described by their level of semantic relatedness: a low semantic relatedness rating (e.g., *hardly-hard*), an intermediate rating (e.g., *lately-late*), and a high rating (e.g., *boldly-bold*). Additional conditions were added where the prime-target pairs shared phonology only (e.g., *spinach-spin*), or shared semantic meaning only (e.g., *idea-notion*). Participants heard the prime word and immediately after the prime word ended, the target word appeared visually on a computer screen for 200 milliseconds. Participants then made their lexical decision to the visual target word as fast as possible. The reaction time data from the experiment show a graded effect of semantic overlap. The prime-target pairs with a high degree of semantic overlap elicited the fastest reaction times (relative to a control unrelated prime), followed by the pairs with an intermediate rating of overlap, which were followed by items that overlapped in semantic meaning only. There was no priming effect for the phonology-only or low semantic conditions relative to the control unrelated prime. The authors argued that the graded effect of semantic overlap on target recognition facilitation supports the claim that the degree of overlap from form and meaning influences the connections of words in the lexicon, which is consistent with the connectionist perspective.

Gonnerman et al. (2007) also included an additional cross-modal priming lexical decision task where the stimuli included various degrees of phonological overlap between prime and target. The stimuli were again morphologically related word pairs. Stimuli included items with no phonological change of the stem (e.g., *acceptable-accept*), phonological difference from a consonant change (e.g., *absorption-absorb*), phonological difference from a vowel change (e.g., *criminal-crime*), and phonological difference from consonant and vowel change (e.g., *introduction-introduce*). The stimuli also included pairs that shared phonology but not meaning (e.g., *accordion-accord*), and items that shared only meaning (e.g., *porpoise-dolphin*). The reaction time analyses revealed a graded effect of phonological overlap in the presence of semantic overlap, though interestingly the greatest facilitation came from pairs with a consonant change, followed by pairs that had no phonological change. Items that overlapped only in phonology (without semantic overlap) offered no facilitation compared to a control prime. The authors took these results as evidence that the degree of phonological overlap between related words modulates the priming effect, which in turn is interpreted as evidence that whole-form lexical items are linked by virtue of their shared form and meaning. The results of the priming tasks are taken as support for the connectionist perspective that the structure of the lexicon is not morphological, but that whole-forms are connected in a network where connections are strengthened by overlap of form and meaning.

It is important to keep in mind that the degree of prime perceptibility itself modulates semantic priming effects between prime and target in behavioral tasks. In cross-modal priming tasks (like Gonnerman et al., 2007), as well as unimodal priming tasks where the prime is not masked (e.g., Rastle et al., 2000), participants are consciously aware of the prime word, as opposed to masked priming where they are not consciously aware of the prime. In tasks where participants consciously perceive the prime, semantic overlap between prime and target offers target recognition facilitation, and a lack of semantic overlap between prime and target can inhibit morphological priming effects. In masked-priming tasks, semantically opaque prime-target pairs (e.g., *corner-corn*) elicit equally fast reaction times as semantically transparent prime-target pairs (e.g., *farmer-farm*). However, when the prime is consciously perceived and identified in the task, only semantically related pairs elicit faster reaction times (e.g., Rastle et al., 2000).

These findings about prime perceptibility and semantic influence have led many researchers to turn to *masked* priming as a means of testing for morphological activation in the lexicon. Given that imperceptible primes heavily diminish (if not completely eliminate) semantic and orthographic priming of the target, masked priming offers an ideal method for adjudicating among morphological models and non-morphological models. Non-morphological models posit that morphology is the convergence of form and meaning, which suggests that when the semantic priming effect is removed by masking the prime, morphological priming should not be found. Morphological models, however, would predict that morphological priming should still be found under masked priming conditions because they posit that morphology is a distinct feature of language (independent of form and meaning), which suggests that morphological priming should still be found in when the prime is masked. Masked priming is thus a powerful tool to adjudicate between predictions from morphological models and predictions from non-morphological models.

The masked priming method

The specific type of priming task that will be the focus of this dissertation is masked priming with lexical decision. Masked priming is unimodal, with both the prime and the target presented visually to the participant. What distinguishes masked priming from other priming methods is that the prime word is presented after a visual mask (e.g., ########), and it is presented for only a very brief amount of time. The combination of the mask and the brief presentation renders the prime word imperceptible at a conscious level for nearly all individuals. In order for the prime to be imperceptible at a conscious level, the duration of the presentation must remain below the perceptual threshold, which is about 60 milliseconds[4] (e.g., Forster & Davis, 1984). Importantly, the letter case of the prime word and the target word must be visually distinct (e.g., lower case letters for the prime, upper case letters for the target). By having the prime and target differ in letter case purely visual priming from letter-shape overlap can be minimized (see K. Forster, Mohan, & Hector, 2003).

In masked priming lexical decision tasks the data of interest is the reaction time to the lexical decision. Priming can be concluded if a certain type of prime-target relationship elicits faster reaction times than a baseline condition where the prime and target are unrelated. The mechanisms responsible for priming have been hypothesized to involve both lower-level prelexical processing levels as well as higher-level lexical levels. Bodner & Masson (1997) claimed that priming effects found in masked priming studies can be attributed to prelexical levels of processing. Their study included a series of masked priming lexical decision tasks where some of the prime-target pairs were identity nonwords (e.g., *shret-shret*). They found priming effects for these nonword repeated pairs, which was used as evidence for a prelexical level of processing contributing to the priming effects in masked priming studies. That is, because there is no lexical entry for *shret*, the priming effect cannot be attributed to lexical activation. The authors argued that priming effects capture orthographic processing and episodic memory effects. However, Bodner & Masson's claims that priming effects are prelexical may be

[4] In Forster & Davis (1984), primes were presented between 20 ms to 67 ms. When primes were 50 ms or less, nearly all participants were unaware that anything happened between the mask and the target. At primes of 60 ms to 67 ms, many participants were aware that something happened on the screen between the mask and target.

limited in their capacity to fully explain the mechanism responsible for priming. A study by Jiang & Forster (2001) demonstrated that masked priming effects can be found in bilingual speakers when the prime and target words are in different languages (with different scripts). Jiang & Forster (2001) tested English-Mandarin bilinguals using a masked priming lexical decision task where the prime was in Mandarin characters and the target was in English. In the related condition, the Mandarin and English words were an exact translation. The results showed significantly faster lexical decision times for the English targets when the prime was the Mandarin translation compared to when the prime was unrelated. The findings in Jiang & Forster (2001) cannot be explained by prelexical orthographic priming because the masked priming effect was found across two languages with two different orthographies.

While the exact mechanisms of the priming effect found in masked priming studies is still debatable, it is reasonable to conclude that a lexical level of processing is a key component in explaining findings across many masked priming studies. Forster & Davis (1984) described the mechanism behind the priming effects in their study as the prime opening the lexical entry, which in turn makes target recognition faster when the target shares a lexical entry with the prime.

Inflectional difficulties in a non-native language

Inflectional morphology is notoriously difficult for non-native speakers of a language. Lardiere (1998a, 1998b) studied the production of verbal morphology in a native Mandarin speaker (“Patty”) who learned English after childhood, and had been living in an English-speaking environment for decades. Despite Patty’s native-like accuracy on pronominal case marking and verb movement, she only produced accurate verbal inflection in about one third of the instances that require overt agreement (e.g., *he walks*). The persistent difficulty with accurate use of inflection suggests that inflectional morphology may be a particularly difficult component of language to learn when the language is learned later in life. Additionally, many L2 psycholinguistic studies in recent years have demonstrated that non-native speakers also show variable sensitivity to morphosyntactic violations on inflected verbs when processing the non-native language (e.g., Hopp, 2010). In many L2 sentence processing studies, learners show reduced or even no perceptible sensitivity to grammatical violations of agreement between subject and verbal inflection, which has led some researchers to claim that non-native speakers have an incomplete or deficient grammar of the second language, and that their grammar is specifically deficient in its instantiation of inflectional morphology (e.g., Clahsen & Felser, 2006; Jiang, 2004).

Perhaps the most influential hypothesis in recent years in the second language literature is the Shallow Structure Hypothesis, put forth by Clahsen & Felser (2006). This hypothesis claims that individuals who learn a second language after childhood are unable to acquire a complete grammar of the second language, and this deficient grammar can explain many of the non-native-like findings in L2 processing studies. The Shallow Structure Hypothesis claims that adult learners are unable to process syntactic structures in a way that resembles how native speakers are able to process language. The claim is that learners do not have access to detailed hierarchical structures and instead must rely on cues from outside of syntax, such as lexical-semantic cues. The motivation for this hypothesis comes from studies that have compared native and non-native speakers on a variety of linguistic aspects, including ambiguity resolution, filler-gap dependencies, and subject-verb agreement sensitivity.

Marinis et al. (2005) used a self-paced reading task to investigate how native and non-native English speakers process filler-gap dependencies in sentences such as 1a and 1b. Participants read sentences broken into 6 regions at their own pace, and answered comprehension questions about the sentences.

> 1a. The nurse *who* the doctor argued ______ that the rude patient had angered _____ is refusing to work late. (Intermediate gap condition)
>
> 1b. The nurse *who* the doctor's argument about the rude patient had angered _____ is refusing to work late. (No intermediate gap condition)

Of interest in the study by Marinis et al. was how structural differences in the presence versus absence of clause boundaries affect reading times. It was hypothesized that sensitivity to the syntactic structure would create a facilitatory effect in items where an intermediate gap is created at clause boundaries compared to items where no such gap is created. It was predicted that the intermediate gaps allow for reactivation of the *wh-* word, which is believed to diminish the processing burden. Whereas the native English speakers showed facilitation (i.e., faster reading times) in sentences where the filler word (i.e., the *wh-* word) could be integrated at intermediate gaps, the non-native English speakers did not show this effect. Additionally, this pattern was found for English learners from a variety of native languages, independent of whether the native language had *wh-* in-situ (Mandarin, Japanese), or *wh-* movement (German, Greek). Clahsen & Felser used such findings to argue that L2 learners are not able to make use of detailed syntactic structures when processing language, and this result is not the consequence of syntactic structures available in the native language. Clahsen & Felser argued that positing potential gaps to reactivate the filler (*wh*-) word requires constructing detailed syntactic structures during reading, and that instead of constructing complex syntactic structures, learners are only able to build more simple (shallow) structures that are lexically driven. That is, whereas native speakers observed the subjacency constraint[5] and reactivate the filler at gaps, it is claimed that the learners instead tried to establish a surface-level connection between the *wh*- filler and the subcategorizing verb.

The Shallow Structure Hypothesis' claims pertaining to how learners process inflectional morphology are much less straight forward compared to its claims on deploying complex syntactic structures, but Clahsen and colleagues' position on learners' ability to process inflectional morphology was expanded and clarified in a more recent review article (Clahsen, Felser, Neubauer, Sato, & Silva, 2010). Clahsen et al. (2010) presented findings on three aspects of morphology in a non-native language: comparing regular and irregular inflectional morphology, derivational morphology, and sensitivity to morphosyntactic violations. They argued that the findings of studies investigating morphological processing in a non-native language are consistent with their hypothesis that learners are less sensitive to the morphological structure of complex words.

Clahsen and colleagues adopt a dual-mechanism perspective on morphological processing for native speakers. In this view (discussed in greater detail above), it is claimed that complex words

[5] Subjacency is a constraint where movements must occur in a series of small steps with "landing sites" at each bounding node (Chomsky, 1973)

can be processed in one of two ways: (i) decomposed into morphological constituents and the morphemes are activated in the lexicon, or (ii) accessed in the lexicon in their whole form. Clahsen and colleagues take the position that lexical access is achieved through such a dual-mechanism in native speakers of a language, and that the distinguishing property that leads to one processing route instead of the other is regularity. They claim that regularly formed words (e.g., *walked*) are decomposable and accessed via morphological units in the lexicon, whereas irregularly formed words (*e.g., went*) are not decomposable, and are accessed in their whole form in the lexicon.

One source that Clahsen and colleagues interpret as evidence of dual-mechanism models comes from frequency effects in behavioral tasks. It has been very well documented over the past decades that more frequent words elicit faster behavioral responses, though the mechanisms responsible for this phenomenon are not yet understood (see Magnuson, 2009, for summary). The claim is that if a regularly formed complex word is decomposed into morphological constituents, the surface-form frequency of the complex form should not influence the speed of a behavioral response (e.g., lexical decision or word naming). Instead, the frequency of the stem morpheme should influence the behavioral response time because it is the stem that will be accessed in the lexicon after the complex word is decomposed into stem and affix. If irregularly formed complex words are stored in their whole-form, the surface-form frequency of the irregular should influence the behavioral response whereby more frequent irregular forms should elicit faster behavioral reactions than less frequent irregular forms.

In their summary of the findings from behavioral studies comparing how learners process regular and irregular inflection, Clahsen et al. (2010) highlighted a number of studies where native and non-native speakers performed similarly for irregular words (e.g., *went*), but the two groups performed differently for regular words. For example, in Babcock et al. (2012), native English speakers and L2 learners of English (Mandarin or Spanish L1) completed a speeded production task that included regular and irregular English past tense forms. For irregular targets, both native and non-native speakers' production times revealed frequency effects (i.e., more frequent irregular forms were produced faster than less frequent irregular forms). This is interpreted as evidence of whole-word storage of irregular words for both the native and non-native speakers. However, the native and non-native speakers differed in the production patterns for the regularly formed words. Native speakers did not show an influence of surface-form frequency on their productions of the regular words, indicating the regularly formed words are stored as morphemes in the lexicon, not unstructured whole words that are susceptible to surface-form frequency effects. The non-native speakers did, however, show surface-form frequency effects in their productions of the regular words, which is interpreted as evidence that the regular forms are stored in their whole-form in the L2 lexicon as unstructured words. Similar findings were found in Silva (2008) in a lexical decision task testing native and non-native English speakers. Clahsen et al. (2010) used these differences of frequency effects as support for the claim that learners are unable to process the morphological structure of regularly formed words, and are consequently unable to decompose complex forms into stem and affix.

Also pertaining to the processing and access of regular and irregular words, Clahsen et al. (2010) discussed findings from an event-related potential (ERP) study on native and non-native German speakers where participants read sentences that contained inflectional violations. In this study by Hahne et al. (2006) stimuli contained morphosyntactic violations of inflection on either a past participle or a noun. More specifically, the violations were either an ungrammatical application of a regular inflection (*-t* on participles, *-s* on nouns) or of an irregular inflection (*-n* on participles, *-n* on plurals)[6]. Native German speakers and native Russian speakers who learned German as a second language read sentences with such violations while electroencephalographic (EEG) data were recorded from their scalps. In both the native and non-native German speakers, the ungrammatical application of a regular inflection on participles elicited a brain response consistent with responses to grammatical rule violations (the P600 component). Both groups also showed a qualitatively different brain response (the N400 component) to ungrammatical use of irregular inflection on participles, indicating that a qualitatively different lexical processing routine was sensitive to the violation. Hahne et al. did, however, find a difference in native and non-native speakers for a third EEG component that is commonly analyzed in morphosyntactic processing studies: The Left Anterior Negativity (LAN). This EEG component is believed to reflect early morphosyntactic analyses during comprehension. In the native German speakers, the LAN response was elicited by the ungrammatical use of regular inflection on both participles and nouns, but the non-native speakers only showed the LAN response for the ungrammatical use of the regular inflection on participles, not nouns. Additionally, the LAN response to ungrammatical participles that was found in the non-native speakers was somewhat different in its scalp distribution compared to the LAN found in the native speakers. Clahsen et al. (2010) argued that the difference in the LAN response for native and non-native German speakers is

[6] Nominal plural inflections in German are not typically described as being “regular” or “irregular”. In the Hahne et al. (2006) study, it is acknowledged that –n has higher frequency as a plural marker, but it is phonologically restricted in where it can appear. The plural –s is the least frequent of the 4 possible plural markers (-n,-s, e, er), but it is the only inflection that is not phonologically constrained, and is the inflection used on novel words.

consistent with claims that non-native speakers have weaker sensitivity to morphological structure compared to native speakers.

What complicates Clahsen et al.'s utilization of the Hahne et al. (2006) study in support of their position is that Hahne et al. concluded that non-native speakers *can* show sensitivity to inflectional structure, though this may depend on proficiency or familiarity with a specific type of inflection (e.g., plurals may be more difficult than participles). When motivating the claim that learners are less sensitive to morphological structure than native speakers, Clahsen et al. instead interpreted the results of Hahne et al. as evidence for weakened sensitivity to the presence of inflection based on the finding that the L2 German group had different LAN responses compared to the L1 German group. Native and non-native speakers showed LAN effects for ungrammatical regular inflection on participles, but only the native speakers showed the LAN effect for ungrammatical regular pluralization on nouns. The interpretation of a qualitative processing difference based on a difference in LAN component is not clearly motivated by Clahsen et al. (2010). The LAN component is relatively less understood in the neurolinguistic literature (compared to other components such as the P600 or N400, both of which were similar in the native and non-native German speakers in Hahne et al.'s study), and this is mostly due to morphosyntactic violations not consistently eliciting a LAN response in native speakers in many studies (see Tanner & Van Hell, 2014 for review). Clahsen et al. (2010) interpreted the findings of studies comparing regular and irregular forms as evidence that non-native speakers are less sensitive to the morphological structure of inflected words.

Clahsen et al. (2010) next compared how native and non-native speakers of a language process derivational morphology. Whereas inflectional morphology transforms words in order to serve a particular grammatical purpose (e.g., subject-verb agreement), derivational morphology leads to a word form that is either semantically different from its root (e.g., *like* and *dislike*), or it creates a word that differs in syntactic category (e.g., *like* and *likeable*). An additional contrast between inflectional and derivational morphology is that unlike inflected forms, derived forms can undergo further affixation (e.g., *unlikeable, likeability*). That is, the result of derivation yields a lexeme, whereas the result of inflection yields a finite word-form. This distinction of inflectional and derivational processes has led some morphologists to claim that the lexicon includes the input lexeme (e.g., *like*) and output lexeme (e.g., *likeable*) for derived forms (e.g., Anderson, 1992). This distinction of the two types of morphological processes is critical in Clahsen et al.'s interpretation of the findings from priming studies (e.g., Silva, 2008; Silva & Clahsen, 2008) that test for sensitivity to morphological structure in a non-native language.

In Silva (2008) and Silva & Clahsen (2008), native English speakers and non-native English speakers (L1 Mandarin or German) completed a series of masked priming lexical decision tasks. The stimuli included three types of prime-target pairs: identity (*bold-bold; acid-acid*), morphologically related (*boldness-bold; acidity-acid*), and unrelated (*rough-bold; small-acid*). The native English speakers showed significant and equivalent priming for the identity and morphological primes compared to the unrelated primes. The non-native speakers, however, showed a different pattern. Compared to the unrelated prime, the non-native speakers were significantly faster to recognize the target word when primed by the identity prime or the morphological prime, but the identity prime elicited significantly faster reaction times compared to the morphological prime. That is, the morphological prime offered some facilitation in target recognition, but not as much facilitation as the identity prime offered.

Clahsen et al. (2010) interpreted the findings in studies such as Silva (2008) and Silva & Clahsen (2008) as evidence that native speakers are able to decompose morphologically structured derived forms into stem and affix, but non-native speakers are less sensitive to the morphological structure, and are consequently unable to decompose derived forms into stem and affix. Clahsen et al. did not, however, offer a clear explanation as to why learners can show some sensitivity to the morphological structure for derived forms but diminished sensitivity for inflected forms (as discussed above). They made reference to previous claims that the combinatorial procedures differ between inflected and derived forms (e.g., Anderson, 1992), but they did not explain why this linguistic difference would result in some sensitivity to the relationship between a stem and its derived form, but no sensitivity to the relationship between a stem and an inflected form. Despite this lack of explanation as the priming differences, Clahsen et al. took the reduced priming of derived forms as further evidence that non-native speakers are more heavily reliant on the declarative memory system to process complex forms in the L2, and less able to make use of the combinatorial processes carried out by the procedural memory system.

Finally, Clahsen et al. (2010) considered findings from morphosyntactic studies to demonstrate the differences in morphological sensitivities between native and non-native speakers. Sato (2007) used a speeded grammaticality test to investigate sensitivity to subject-verb agreement violations and case violations in non-native speakers of English (L1 of German, Japanese, or Mandarin). Participants were visually presented with short phrases (e.g., **we regularly sneezes,*

**he admires she*), with each word appearing in isolation for 350 milliseconds. After reading the phrases, participants made a grammaticality judgment as quickly as possible. The accuracy analyses on the ungrammatical phrases showed that native English speakers were equally sensitive to subject-verb agreement violations and case violations, but all groups of non-native English speakers were significantly less sensitive to subject-verb agreement violations than case violations. Similar results of learners demonstrating reduced sensitivity to subject-verb agreement violations compared to other grammatical violations have also been found in grammaticality judgment tasks with auditory stimuli presentation (e.g., McDonald, 2000). A number of other methodologies provide additional support that non-native speakers are less sensitive to subject-verb agreement violations in online sentence reading tasks (e.g., Chen et al., 2007); Jiang, 2004, 2007; Keating, 2009). Clahsen et al. (2010) took these findings of diminished sensitivity to subject-verb agreement violations as further support for their claim that non-native speakers are less sensitive to the morphological structure of inflected words compared to native speakers.

Given the evidence they gathered from previous studies, Clahsen et al. argued that non-native speakers are less sensitive to the morphological structure of complex words compared to native speakers, and claimed that these findings were consistent with Ullman’s Declarative/Procedural approach to lexical processing. Ullman’s (2005) model claims that native speakers make use of two distinct memory systems during lexical processing: the declarative memory system, which subserves the lexicon, and a procedural memory system which is responsible for carrying out combinatorial and decompositional procedures. Ullman claims that non-native speakers are forced to rely heavily on the declarative memory system to process the L2 because access to the procedural memory system is significantly weakened. It thus follows from this L2 model that non-native speakers would be unable to analyze the morphological structure of complex forms, and instead need to make use of a lexical entry for the complex word. Clahsen et al. argued that the findings that they reviewed were indeed consistent with Ullman's claim. Specifically, for the types of words that native speakers are claimed to store in their whole form (e.g., irregular past tense verbs), non-native speakers show similar patterns, and it is claimed that they are native-like in their storage and processing of these forms. However, for the types of words that native speakers are believed to analyze via procedural memory and decompose into morphological constituents (e.g., regularly inflected forms), the non-native speakers do not show a similar pattern of results as the native speakers. In fact, the non-native speakers show similar patterns for their processing of irregular and regular forms, indicating that all forms are being processed as unanalyzed forms that are stored in their whole-form in the lexicon.

There is one important point of consideration between Ullman's (2005) Declarative/Procedural model and Clahsen et al.'s interpretation of how Ullman's model fits with the findings of non-native morphological processing studies. Ullman hypothesized that the decreased access to procedural memory for languages learned later in life is the consequence of biological maturation. He claimed that the availability and ability to learn differs over the lifespan for the declarative memory system and the procedural memory system. Specifically, in childhood the procedural memory system is claimed to be readily available for learning, but declines in its availability for learning in adolescence. The trajectory of availability differs for the declarative memory, which is less available for early childhood learning, but improves into adolescence and adulthood. A crucial component of his model is that neither memory system is ever completely unavailable to learning. In a recent review of the Declarative/Procedural model in Morgan-Short & Ullman (2012), it is emphasized that learning (language or otherwise) is accomplished more quickly via the declarative memory system compared to the procedural memory system, so along with the relatively more-available declarative memory system, it is claimed that L2 learning will initially be carried out via the declarative memory system. It is emphasized that learning via the procedural memory system does indeed happen in adults, and language learning is no exception. It is hypothesized by Ullman (2005) (and later re-emphasized by Morgan-Short & Ullman, 2012), that adult L2 learners will be able to increasingly make use of the procedural memory system to carry out grammatical analyses (including morphological processing). Note that it is not the claim of Ullman's model that information learned via the declarative memory system will be proceduralized and transformed into information held in the procedural memory system. That is, the declarative information does not simply become procedural information and cease to remain in declarative memory. Instead, it is predicted that the procedural system becomes more available to learn procedural knowledge that can be applied to language processing. This increased availability of procedural memory resources can consequently lead to redundant information (i.e., information that leads to the same outcome can be found in both memory systems). Importantly, it is predicted that proficiency is the driving force that will lead to the procedural memory system carrying out grammatical processing. Morgan-Short & Ullman (2012) also considered that learning environment and the type of information that needs to be proceduralized may additionally play a role in the ability to proceduralize certain language processing procedures.

Where Ullman's predictions diverge from Clahsen et al.'s (2010) claims of reduced ability to process morphological information is in their predictions about the potential for increased proceduralization of L2 grammatical processes. In both Clahsen & Felser (2006) and Clahsen et al. (2010), differences between native and non-native speakers are discussed as though they are static and permanent. That is, Clahsen and colleagues treat the reduced sensitivity to morphological structure as a fundamental difference between how native and non-native speakers represent the language in the brain, and increased proficiency or experience with the language will not modulate this difference. Ullman, however, predicts that the initial stages of adult language learning are indeed qualitatively different from native speakers in terms of how grammatical structures are stored and processed in the brain, but this qualitative difference is predicted to change with experience and proficiency. Ullman predicts that native-like sensitivity to morphological structure, and a native-like ability to decompose complex forms into stem and affix is in fact possible.

Aim of this dissertation

This dissertation aims to further investigate how native and non-native speakers process regular verbal inflections. While previous literature has provided much evidence that non-native speakers are sensitive to the morphological structure of derived complex forms (e.g., De Grauwe, Lemhöfer, Willems, & Schriefers, 2014; Diependaele, Duñabeitia, Morris, & Keuleers, 2011; Silva & Clahsen, 2008), strong claims have been made by some researchers that learners are unable to process inflectional morphology in a native-like way (e.g., Clahsen et al., 2010). Despite many studies aiming to test if non-native speakers are able to show native-like sensitivity to inflection the evidence in either direction remains unclear. This dissertation aims to address a number of methodological issues that have contributed to an unclear understanding of how adult learners of a language process inflectional morphology. Additionally, there are two competing hypotheses about the role of proficiency in the ability to process inflected forms in a native-like way. Ullman predicts that with increased proficiency, learners will undergo a qualitative shift in their processing abilities regarding regular inflections. Specifically, lower-level learners are expected to store regularly inflected words in their whole-form in the lexicon, whereas higher-level learners are predicted to decompose inflected forms into stem and affix via the procedural memory system. Conversely, Clahsen and colleagues do not make such a prediction, and instead treat non-native-like sensitivity to morphological structure as a permanent feature of the L2 grammatical representation. Finally, this dissertation adds to the current body of literature by using French as its language of study. The field of L2 morphological processing has predominantly (though not exclusively) focused on English and German. The addition of French to this growing literature contributes to our understanding of morphological processing in general, and contributes to our understanding of how specific language properties may be important to consider when generating theories of second language acquisition.

Two studies use a masked priming lexical decision task to test if native English speakers who learned French as a second language after childhood are able to demonstrate the ability to decompose regularly inflected French verbs into stem and affix. Additionally, these studies test if the ability to decompose inflected forms is modulated by proficiency in the L2. In the next chapter (Chapter 2), a masked priming lexical decision task with native and non-native French speakers is presented, and its findings discussed. Chapter 3 presents a masked priming lexical decision during EEG recording with a similar participant population, and its findings are discussed. Chapter 4 provides an overall conclusion to this dissertation, and presents possible paths for future research.

Chapter 2: Experiment 1

Introduction

As discussed above, inflectional morphology is notoriously difficult for non-native speakers of a language (e.g., Lardiere, 1998). By contrast, learners are often highly accurate with the use of derivational morphology (e.g., Lardiere, 2006). The trouble with inflectional morphology has been well documented in the psycholinguistic literature over the past two decades, where many studies have provided many examples of non-native speakers showing diminished sensitivity to morphosyntactic errors in listening and reading tasks (e.g., Johnson & Newport, 1989; Jiang, 2004). This chapter focuses specifically on studies testing for sensitivity to inflectional morphological structure in a non-native language, with specific focus on studies that used priming as the method of investigation. These topics are the focus of discussion because Experiment 1, presented in this chapter, uses a masked priming lexical decision task to test if non-native French speakers are able to show native-like sensitivity to verbal inflection.

As introduced above, Clahsen & Felser have put forth a hypothesis that claimed that the reason why adult learners of a second language have such persistent difficulty with inflections in speech, and show such diminished sensitivity to ungrammatical use of inflections in reading, is that there is a fundamental difference in the grammar of a language learned later in life compared to the grammar of a native language or a second language learned during early childhood. In particular, the L2 grammar is deficient in its representation of inflection. The Shallow Structure Hypothesis (Clahsen & Felser, 2006) and a later iteration of the hypothesis specific to morphological processing (Clahsen et al., 2010) posit that adult learners of a language have an incomplete grammar that does not contain morphological structure for inflected forms. Clahsen and colleagues' hypothesis claims that adult learners are insensitive to the morphological structure of inflected words and are unable to make use of the morphological processing route available to native speakers (see discussion above about native processing models).

Much recent work by Clahsen built upon this claim of a lack of morphological sensitivity by testing whether adult learners of a language are able to decompose morphologically complex words into stems and affixes, as native speakers are able to do. His work testing verbal inflections, discussed in detail below, has consistently failed to provide evidence of morphological decomposition for inflected words in a non-native language, which led him and his colleagues to conclude that languages learned later in life do not have access to the brain mechanisms responsible for morphological decomposition of inflected verbs, and late L2 learners are consequently forced to store complex forms in their whole-form in the lexicon. Consistent with the Shallow Structure Hypothesis' claims, Clahsen and colleagues' recent work on processing inflected words in the L2 has been taken to suggest that neither increased proficiency in the second language, nor properties of the native language and second language will change this lack of sensitivity to inflectional structure.

Non-native-like processing of inflection in an L2: Evidence from priming

The claim that adult learners are not able to decompose inflected verb forms comes predominantly from masked priming lexical decision tasks (see above for details about this method). Silva & Clahsen (2008) used such a task to investigate if adult learners of English who were native speakers of German, Mandarin, or Japanese were able to show evidence of morphological decomposition. The study included multiple experiments which tested sensitivity to verbal inflections (e.g., *boiled*, *kicked*) as well as derivational morphology (e.g., *humidity, boldness*). Including tasks with different types of morphologically complex words (inflection and derivation) allowed the authors to test if non-native speakers were able to show evidence of decomposing various kinds of morphologically complex words. Each experiment in the study included three types of prime-target relationships: identity (e.g., *boil-BOIL*), morphological (e.g., *boiled-BOIL* in the inflectional experiments*; boldness-BOLD* in the derivational experiments), and unrelated (e.g., *jump-BOIL*). There was an additional manipulation of prime presentation duration for the tasks using verbal inflection as the morphological test condition: the prime was either presented for 30 ms or 60 milliseconds. This manipulation was introduced to test if the learners were able to demonstrate sensitivity to morphological structure but required more time to process the prime word. The study included English learners from a variety of native language backgrounds (matched on English proficiency) to test if the similarity between native and second language had an influence on the ability to process morphologically complex words in a native-like way. Language similarity was qualified based on the presence of inflection and derivation in the various native languages of the L2 English speakers. Of the three language groups in the study, German is described as being most similar to English because it has regular past tense verbal inflection (-*te*) and deadjectival derivational morphemes (-*heit/-keit, -ität*). Japanese is considered next most similar to English in that it has a regular past tense verbal inflection (-*ta*), though does not have derivational morphemes. Mandarin is considered the most distinct from English because it lacks both inflectional and derivational morphemes.

Before discussing the results of this study, it is important to note what outcome Silva & Clahsen would consider as evidence of morphological processing. The priming studies Clahsen has contributed to discuss three possible outcomes regarding comparisons between the three conditions (identity, morphological, and unrelated). The first potential outcome of a priming study with these conditions is referred to as *full priming*. This outcome is one where targets with identity primes are recognized significantly faster than targets with unrelated primes, and targets with morphological primes are also identified significantly faster than targets with unrelated primes. Crucially, in this outcome, there is no significant difference in target recognition speed between the identity and morphological prime conditions. Essentially, *full* priming is claimed to be the result of a morphological prime being decomposed into stem and affix, and the stem is activated in the lexicon, which is predicted to lead to equally fast lexical decision times as compared to when the prime is the stem. The second possible outcome of this kind of priming study is called *partial priming*. This outcome is one where targets with identity primes are recognized significantly faster than targets with unrelated primes, and targets with morphological primes are also identified significantly faster than targets with unrelated primes. The critical difference between *full* priming and *partial* priming is that in *partial* priming, the targets with identity primes elicit faster lexical decision times compared to targets with morphological primes. That is, there is facilitation from morphological primes compared to unrelated primes, but the facilitation is significantly weaker than the facilitation from identity primes. Such a finding would be interpreted by Clahsen and colleagues as evidence that the morphological prime was *not* decomposed into stem and affix, but instead the inflected form is stored in its whole-form in the lexicon, and the facilitation in lexical decision speed is due to overlap in lexical entries of related words. The third possible outcome in this kind of study is *no priming*.

This outcome is one where the targets with identity primes elicit significantly faster lexical decision times than targets with unrelated primes, but there is no significant difference between morphological primes and unrelated primes. It is important that at least identity priming is found in these types of studies because otherwise there would be no evidence that the task works at all. In the case of no priming, it would be concluded that the shared morphology between prime and target offers no facilitation at all compared to unrelated primes due to a complete lack of sensitivity to the morphological structure of complex words.

In Silva & Clahsen the results of the experiments that included derivational morphemes showed that native English speakers were equally fast in responding to target items primed either by an identity or morphologically related word (e.g., *boldness-BOLD*, *humidity-HUMID*), and in both of these conditions they were significantly faster compared to when primed by an unrelated word (e.g., *rough-BOLD, loud-HUMID*). The native English speakers show *full* priming of derived words. The English learners, however, showed a different priming pattern: *partial* priming. The learners were significantly faster in their lexical decision when the prime was identical to the target when compared to when the prime was unrelated to the target. They were also significantly faster to respond to the target when the prime was morphologically related to the target compared to when the prime was completed unrelated. Where the learners differed from the native speakers was that the learners showed significant significantly less facilitation from the morphologically related primes than the identity primes. For derived words, learners showed some facilitation from morphologically related words, but they did not show evidence of stem activation in the lexicon as a result of morphological decomposition.

In the experiments testing verbal inflections in the morphologically related prime condition (e.g., *boiled-BOIL*), the native English speakers again showed significant and equivalent facilitation in target recognition when the prime was either identical or morphologically related to the target compared to when the prime was unrelated to the target (i.e., *full* priming). The learners, however, only showed significant facilitation in the identity condition compared to the unrelated condition. That is, there was no significant difference in lexical decision times when the prime was morphologically related to the target compared to when it was unrelated to the target (i.e., no priming). This was true for all native language groups. The authors argue that their results are consistent with claims that learners are insensitive to the morphological structure of inflected forms, and are unable to make use of the decompositional processes that strip stem and affix in an inflected form.

This difference in processing between derived and inflected forms led the authors to conclude that learners have at least some sensitivity to the morphological structure of derived words (though to a lesser extent than native speakers), but not to the morphological structure of inflected words. The authors posited that this difference in morphological sensitivity between derived and inflected forms may be best understood through the differences in linguistic processes available to each type of word. Whereas derived forms can further undergo derivation (e.g., *affordable* → *unaffordable*), only one inflection can be added to a stem (e.g., *walks* cannot take additional inflection). Silva & Clahsen suggested that this difference between derivation and inflection leads to different sensitivities to the morphological structure for non-native speakers. They speculated that the lack of sensitivity to inflection specifically may be the consequence of their grammar lacking functional categories such as inflection or functional features such as past tense marking, as proposed by earlier L2 studies (e.g., Hawkins & Chan, 1997; Meisel, 1991). That is, they suggested that the lack of certain grammatical features (like inflection or tense) may explain why learners are insensitive to the morphological structure of inflected words, though they are sensitive to other morphological structures that are not subject to verbal inflection.

To summarize, Silva & Clahsen posited that learners are sensitive to the stem-affix structure of derived forms, and will activate the stem in the lexicon when the derived form is presented as a prime word because their grammar is not deficient in its instantiation of the derivational processes. They claimed that this process is less efficient in the L2 than it is in the L1 (as demonstrated by partial- rather than full-priming), but that for derived forms, native and non-native speakers are sensitive to the morphological structure. By contrast, they suggested that the learners' grammar is deficient in the domain of inflection, and this deficiency forces learners to rely heavily on storing inflected words as separate lexical entries that are not analyzed as containing morphological structure.

The results of Silva & Clahsen (2008) can be interpreted as further evidence for Clahsen and colleagues' claims that learners' grammars may be deficient in their representation of verbal inflection, and this is not modulated by language pairings of the native and second language. Additionally, the learners were all of advanced proficiency in English[7], so it is unlikely that poor proficiency can explain their findings. Clahsen and colleagues have carried out a number of other

[7] The native German and Mandarin speakers completed the Oxford Placement Test (Allan, 1992), and the range of scores for both groups was 166–170 (out of 200), which is described as an advanced/proficient English user. The native Japanese group completed the International English Language Testing System exam (www.IELTS.org), and scored 5.5 – 7 with a mean of 6.36 (out of 9), which is described as a competent user. Silva & Clahsen conclude all learners were "advanced learners of English".

similar studies using a variety of language pairings to further investigate if learners are able to show evidence of morphological processing of inflection. Their studies on Polish-speaking learners of German (Neubauer & Clahsen, 2009), Arabic-speaking learners of English (Clahsen et al., 2013), and learners of Turkish from a variety of native languages (e.g., Kirkici & Clahsen, 2013) also failed to find evidence of morphological processing of inflected forms in a masked-priming lexical decision task.

Using a different task, cross-modal priming with word-naming, Jacob, Fleischhauer, & Clahsen (2013) tested if native Russian speakers who learned German after childhood are able to process past participles carrying the inflections *–t* or *–n* in a native-like way. In this task, participants heard an auditory prime word, followed by a visually presented target word. The participants then said the target word aloud as quickly as they could. Their naming latency was used as the dependent variable in the analyses. The stimuli included three conditions relating to the prime-target relationships: identity, morphologically related, and completely unrelated. The morphologically related primes included three kinds of verbal inflections: (i) verbs that took the regular *–t* inflection (e.g., *gedruckt-drucke*, 'printed-print'); (ii) irregular *–n* where the stem form does not undergo phonological change (e.g., *gebacken-backe*, 'baked-bake'); (iii) and irregular *–n* where the stem does undergo phonological change (e.g., *gestohlen-stehle*, 'stolen-steal').

The results of this study show that native German speakers showed *full* priming for the regular *–t* inflected forms, and *partial* priming for the irregular *–n* inflected forms. The stem allomorphy did not modulate the priming effect in the native German speakers. The authors claim the different priming effects for *–t* and *–n* reflect different processing routines for regular and irregularly formed words whereby only regular forms (i.e., participles with *–t*) undergo morphological decomposition, and irregular forms (i.e., participles with –*n*) are stored in their whole-form in a lexical subentry that overlaps with the lexical entry for the verb's stem.

The results for the learners of German were similar to the native Germans for one of the conditions and different from the native Germans in the other two conditions. The learners showed *partial* priming for the regular –*t* items as well as for the irregular –*n* items where the stem undergoes phonological changes. The learners showed no priming for the irregular –*n* items that do not undergo phonological changes to the stem. The authors argue that, similar to the findings in masked priming lexical decision tasks discussed above, the learners are unable to decompose the regularly inflected forms, and this is why they do not show *full* priming for items inflected with –*t*, like the native speakers do. The condition in which the learners do behave like the native German speakers is the –*n* with stem changes condition where both groups show *partial* priming. It is argued that both groups are storing these forms in their whole-form in the lexicon, and the (partial) priming effect is the result of the lexical entry for the complex form overlapping with the lexical entry of the stem form. Unlike the native speakers, the learners showed no priming in the –*n* (no stem change) condition, which was not in line with the authors' predictions. If the participle is stored in its whole-form, it is expected to overlap with the lexical entry of the stem, and thus elicit partial priming. The authors speculate that one explanation for the finding could be that in the –*n* (no stem change) items (e.g., *gebacken*, 'bake'), the infinitive form (*backen*) is completely embedded in the participle, and it is possible that the infinitive form is co-activated in the lexicon, which consequently leads to competition that prevents measurable priming effects. This argumentation is based on the speculation that the learners will be more familiar with the infinitive form of a verb compared to any inflected form of the same verb due to its use as the citation form and the infinitive typically being presented in the classroom for learning, which could make the infinitive form prominent when the participle is presented. This explanation for the unexpected findings does not seem to be consistent with other claims in the study. The authors argue that learners are relying more heavily on whole-word storage than native speakers do for inflected words, and that learners have diminished ability to analyze the morphological structure of complex forms compared to native speakers. It appears contradictory to argue that they are insensitive to the internal structure of words while also suggesting that the learners are sensitive to the presence of the infinitive form embedded within the participle, but the logic of how this happens is not clearly explained. It may indeed be the case that learners co-activated the infinitival form which in turn masked any evidence of activating the lexical entry for the participle. The possibility that priming took place but was not measurable in the task that was used may be taken to suggest that the task was not an ideal tool to investigate how learners process morphological information. The task used in Jacob et al. (2013) was indeed quite complex in that it included an auditory component (prime presentation), a visual component (target presentation), and a production component (elicited response). Given the demands of the task, it may be difficult to determine the point at which learners' processing is qualitatively different from native speakers. That is, the task itself may be clouding our understanding of native and non-native linguistic differences.

Native-like processing of inflection in a second language

The studies discussed in the section above failed to find sensitivity to inflection in non-native speakers, though there is evidence suggesting sensitivity to derivational morphology in non-native speakers. Clahsen and colleagues have used such findings as support for the claim that the

L2 grammar is deficient in its instantiation of inflectional morphology, and this leads to diminished sensitivity to morphological structure in inflected words (e.g., Clahsen et al., 2010).

The prediction by Clahsen and colleagues that proficiency and experience with the language will not influence a learner's ability to process morphological information is opposed by Ullman (2005) who extended his Declarative/Procedural model (Ullman, 2001) to adult learners of a second language. Recall that Ullman predicted that at lower levels of proficiency in a second language learners do not have access to the brain mechanisms responsible for carrying out grammatical procedures (like decomposition), and instead are forced to over-rely on the brain mechanisms responsible for storage. However, he predicts that with increased proficiency learners would be able to gain access to the procedural mechanisms and begin to decompose regularly formed complex forms, similar to native speakers. There is in fact some research that is in line with Ullman's predictions that non-native speakers are able to decompose inflected words into stem and affix, like native speakers do, though it is still unclear if (or to what extent) proficiency and L1-L2 pairing may influence sensitivity to inflectional morphology.

Basnight-Brown et al. (2007) used a cross-modal priming lexical decision task to test if native Serbian and native Mandarin speakers who learned English after childhood were able to process regularly and irregularly formed English past-tense verbs in a native-like way. Including Serbian and Mandarin speakers allowed the researchers to test if inflectional properties of the native language influence the capacity to process inflection in the second language. Serbian is a highly inflected language, whereas Mandarin lacks verbal inflection. In this experiment participants heard a prime word and were then visually presented with a target word. They then made a lexical decision for the target word as quickly as possible. The stimuli included morphologically related prime-target pairs (e.g., *drawn-draw; pushed-push*) as well as unrelated pairs (e.g., *drain-draw; paused-push*). The native English speakers showed priming effects for both the regular and the irregular past-tense forms, suggesting they processed complex forms morphologically independent of regularity. The native Serbian speakers were native-like in their processing of regular and irregular forms, whereas the native Mandarin speakers were only native-like in their processing of regular forms. While the incorporation of irregular forms in the study is interesting, and the findings are important within the broader context of morphological processing, what is pertinent to the present discussion is the findings for the regular forms. The on-going debate in the L2 literature concerns whether non-native speakers can decompose regularly inflected forms. The results in the Basnight-Brown et al. study suggest that learners can indeed show evidence of morphological processing, and properties of native language do not appear to influence the ability to process regular verbal inflection.

Evidence for morphological processing in a non-native language is also found in another cross-modal priming lexical decision task in Feldman et al. (2010), who also investigated English past tense verbs with Serbian learners of English. The prime-target pairs where either morphologically related (*billed-bill*), orthographically related (*billion-bill*), or completely unrelated (*careful-bill*). The results of the cross-modal priming task showed that both native and non-native English speakers were significantly faster in their lexical decision time to the target word when primed by a morphologically related word compared to an unrelated word. The facilitation from the morphologically related prime was also significantly greater than any facilitation from orthographically related primes. The Feldman et al. (2010) study also included a masked-priming lexical decision task with the same stimuli as were used in the cross-modal priming study. In the lexical decision task, the prime was visually presented for 48 ms, followed by the visual target word. Interestingly, both native and non-native speakers again showed facilitation in target recognition when the prime was morphologically related compared to when the prime was unrelated to the target, and the facilitation from morphologically related primes was greater than any facilitation from orthographically related primes. When the learners were split into a high and low proficiency group, only the high proficiency group showed the native-like effects. The findings of Feldman et al. are important in that they show that lexical decision tasks can find evidence of morphological processing of inflection, and also that proficiency in the language may influence the ability process inflection in a native-like way. However, proficiency was measured by splitting groups into high and low proficiency groups based on accuracy and speed in the tasks, so the conclusions about proficiency effects should be interpreted with caution.

The results from both the Basnight-Brown et al. (2007) and the Feldman et al. (2010) studies do indeed provide evidence that learners are able to show evidence of morphological processing. In both studies, an inflected aural or visual prime elicited faster lexical decision times to a morphologically related stem target when compared to lexical decision times in trials where the prime was unrelated. Additionally, the morphological facilitation in Feldman et al. (2010) could not be attributed to the fact that morphologically related words overlap in form (orthographic or phonological) because the morphological primes elicited faster reaction times than primes that overlapped in orthography (but not morphology). Such results indicate that the facilitation was indeed morphological in nature. However, Clahsen and colleagues do not accept the results of these studies as evidence that non-native speakers are able to decompose morphologically complex words into stem and affix, and their rejection is based on the lack of an identity condition in both the Basnight-Brown et al. (2007) and the Feldman et al. (2010) studies. Clahsen and colleagues state that morphological decomposition can only be claimed when morphologically related primes offer equal facilitation compared to identity primes (i.e., *full* priming). Their position is clearly stated in Jacob et al. (2013), "…that we assume FULL PRIMING to signify a stem-repetition priming effect and PARTIAL PRIMING to indicate a shared lexical entry for the prime and the target word form" (pg. 930, emphasis in original). Given that they necessitate evidence of *full* priming to argue morphological decomposition and morphological processing, identity conditions are consequently required as a test condition. It is important to keep in mind that this requirement to find *full* priming in order to argue morphological processing was proposed by Clahsen and colleagues, and is not a widely held standard in the native literature investigating morphological processing (e.g., Estivalet & Meunier, 2015; Penke et al., 1997; Smolka, Gondan, & Roesler, 2015). In the native literature, morphological priming that cannot be attributed to orthographic or semantic priming is generally interpreted as evidence of morphological processing; a comparison to identity priming is not seen as necessary to make this conclusion. Clahsen and colleagues, however, believe that if morphological decomposition is in fact taking place, morphological priming should consequently be equivalent to identity priming (using stem forms). Their position is that morphological priming is not sufficient on its own to conclude that decomposition and morphological processing have taken place.

In a previous study, I incorporated an identity prime condition, which put the study in a position to test if non-native speakers are able to show *full* priming from inflected words. Coughlin & Tremblay (2015) used a masked priming word-naming task to investigate if native English speakers who learned French after childhood are able to show evidence of morphological decomposition. A prime word was visually presented for 50 ms, followed by a target word. Participants said the target word as quickly as they could, and their production latencies were measured and analyzed. The verbal inflection that was tested was the first-person plural *–ons* (e.g., *donnons*, '(we) give'). There were five conditions of prime-target relationships: (i) identity (e.g., *donne-DONNE*¸ 'give-GIVE'), (ii) morphological (e.g., *donnons-DONNE*), (iii) orthographically (e.g., *doute-DONNE*, 'doubt-GIVE'), (iv) semantically (e.g., *sert-DONNE*, 'serve-GIVE'), or (v) unrelated (e.g., *parle-DONNE*, 'speak-GIVE'). By including the additional conditions of orthographically and semantically related primes, this study was in the position to be able to test not only for *full* priming, but also to test if any facilitation from morphologically related primes could be attributed to shared orthography or shared semantics between prime and target words.

The results of the masked priming word-naming task showed that both native and non-native French speakers were equally fast to name the target word when the prime was either identical or morphologically related to the target, and both identity and morphological primes elicited significantly faster naming latencies than unrelated primes. In other words, both native and non-native French speakers showed *full* priming effects, which suggests the morphologically complex words were decomposed into stem and affix, and a morphological unit was activated in the lexicon. When proficiency (as measured by a cloze test) was included in the analyses of the non-native French group, the results show that all learners show the *full* priming effect, but as proficiency increases the priming effect increases. Importantly, the inclusion of the orthographic and semantic conditions allowed us to demonstrate that the morphological facilitation found in the native and non-native French speakers cannot be attributed to the fact that morphologically related words overlap in orthography and meaning. The facilitation from morphologically related primes was statistically greater than any facilitation from orthographically or semantically related primes. The findings in this naming study are in opposition to the results of Jacob et al.'s (2013) naming study with learners of German.

The results from Coughlin & Tremblay (2015) provided evidence that the mechanisms responsible for morphological decomposition are indeed available to non-native speakers who learned their second language after childhood, which runs counter to claims by Clahsen and colleagues. By contrast, these findings are in line with the predictions by Ullman (2005) that native-like processing of inflectional morphology is possible in a language learned later in life. One point to note about Ullman's predictions is that he claimed that increased familiarity and proficiency in the language are the factors that will lead to native-like processing of inflectional morphology, but this part of his prediction was not borne out in the results from Coughlin & Tremblay (2015). The results of the word-naming task showed that increased proficiency led to increased priming, but even the lower-level learners were showing evidence of morphological processing. One potential explanation for the lack of qualitative shift may be that the learners in the study were of high enough proficiency when they completed the study, and had already gone through the shift. Given that the task required participants to be fast and accurate in their productions, lower-level learners were not targeted to participate in the experiment. It is possible that learners in the study had already gone through a transition of not being able to decompose to being able to decompose.

The studies discussed above provide an unclear picture of whether, and under what circumstances, non-native speakers are able to show evidence of decomposing inflected forms into stem and affix, and accessing a morphological level of representation in the lexicon. Experiment 1 aims to address a number of limitations in previous studies that have contributed to an unclear understanding of how non-native speakers process verbal inflection. Experiment 1 uses a masked priming lexical decision task to test if native English speakers who learned French after childhood are able to show evidence of decomposing inflected forms into stem and affix, and access a morphological level of representation in the lexicon. This method is considered a powerful tool in studying morphological processing, and using it in here puts Experiment 1 in a position to test the claims made by Clahsen and colleagues based on similar tasks.

In addition to using masked priming, the inflection under investigation puts Experiment 1 in a position to address limitations of some previous studies. Similar to Coughlin & Tremblay (2015), the first-person plural inflection *–ons* is used as the test inflection, and all test targets are regular *–er* French verbs. The French inflection *–ons* has a number of properties that allow Experiment 1 to adjudicate between *morphological* versus *non-morphological* processing, which are discussed further below. Finally, Experiment 1 tests a wide range of French proficiency which is critical to a study's ability to test Ullman's (2005) prediction of a qualitative shift. By testing a range of proficiency levels, Experiment 1 will be in an ideal position to investigate if lower-level learners are forced to rely on whole-word storage of inflected forms, but with increased proficiency, higher level learners are able to gain access to the mechanisms responsible for decomposing inflected words in the L2. By incorporating these elements into the study's design, Experiment 1 is in a strong position to test the claim that adult learners are non-native-like in their sensitivity to inflectional morphology.

Experiment 1: masked-priming lexical decision

Participants

Thirty-five native French speakers (29 females) participated in the study (age range 18-45 years; mean 21.4 years). Participants were all born and grew up in France, and were enrolled as students in psychology at a French university at the time of testing. Participants received psychology course credit for their participation. There was only one participant at the higher end of the age range (above 26 years). This participant's mean reaction times were compared to the reaction times of the other native French participants. This comparison revealed no difference in mean reaction times (her mean reaction time is slightly faster than the mean of the other 34 participants). This participant also did not differ in accuracy rates compared to the other participants. Her data were included in the analyses.

In addition to the native French speakers, 25 native English speakers (19 females) who learned French as a second language also participated in the study (age range 18-48 years; mean 21.8 years). Participants were born and grew up in the United States or English-speaking Canadian provinces, and were either enrolled in or teaching at least one French language course at the University of Kansas at the time of the study. All participants grew up in a household where

English was the only language, and no participant was exposed to French before age 10. There was only one participant at the higher end of the age range (above 27 years). This participant's mean reaction times were compared to the reaction times of the other non-native French participants. This participant's mean reaction times were towards the high-end compared to all other participants, but his mean reaction times were not the highest in the group. Additionally, his accuracy in the task was near ceiling. His data were included in the analyses.

In addition to the main lexical decision tasks, the non-native French speakers completed a language background questionnaire (Appendix A) , a cloze test to measure their proficiency in French (adapted from Tremblay, 2011) (Appendix B), and a LexTale-inspired French lexical decision task designed to measure proficiency (Appendix C). A summary of the ranges, means, and standard deviations for age of first exposure to French (AoE), years of French instruction (Yrs Inst), weekly percent French use (%French), months of French immersion (Immersion), cloze Score out of 45 (Cloze), and LexTale percentage (LexTale) are provided in Table 2.1 below. The proficiency measures are described in greater detail below.

Table 2.1. Language background and proficiency for L2 French group

	Age	**AoE**	**Yrs Inst**	**%French**	**Immersion**	**Cloze**	**LexTale**
Mean	21.8	15.8	5.4	10.7	3.3	23.7	0.61
Range	18 – 48	12 – 27	2 – 15	2 – 35	0 – 38	11 – 39	0.49 – 0.84
St. Dev	5.7	3.5	2.9	9.0	8.3	6.7	0.08

Non-native French proficiency measures

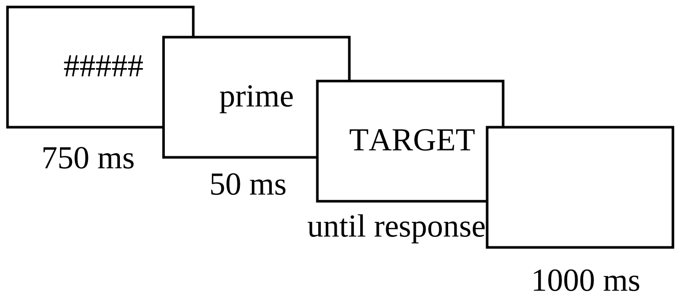
The first proficiency measure that the non-native French group completed was a cloze test (fill-in-the-blank) with multiple choice options. The original version of this test comes from Tremblay (2011), which was completed on paper and participants were not given words to choose from to complete the blanks. The particular version of the task used in the present study was completed on a computer where participants were presented with a paragraph with 45 blank spaces. This change was implemented to allow participants to complete it in less time to reduce fatigue (approximately 20 minutes compared to 40 minutes for the paper version). One at a time, a blank space was bolded to visually stand out, and four options were presented at the bottom of the screen. Participants used the computer mouse to select which of the four options best fit the blank space to complete the paragraph. Once a selection was made for a given blank the participants could not go back and change their selection. Participants were told that the task was designed to be difficult, and that they should take as much time as they needed to do their best. Most participants took between 15 and 20 minutes to complete the task. The materials for this task, including the multiple options for each blank are provided in Appendix B.

The second proficiency task was a lexical decision task inspired by the English proficiency task LexTale (Lemhöfer & Broersma, 2012). In the task used in the present study, participants are presented with strings of letters and must decide if they are real French words or not. They are not put under time pressure, and they are instructed that they should err on the side of saying a string of letters is not a word if they are unsure. They are told that if they are presented with a non-word and they respond that it is a word, they would lose points, so they should be careful to respond “word” only to items they are sure are real French words. The real words in the task vary in their frequency, from moderately frequent words (e.g., *honnêteté*, 'honesty') to very infrequent words (e.g., *langui*, 'languish'). The rationale behind this task is that familiarity with infrequent words will correlate with proficiency in French, and by instructing participants to only respond "word" when they are sure of the lexical status of an item, their proficiency in the language can be approximated. The non-word items are designed to look like possible French words, and include orthography that looks morphological in nature (e.g., **couprir,* appearing to be an *–ir* infinitive verb form) so the participants are unable to rely on perceived word structure as a cue to lexical status. Scoring is done by first averaging the accuracy for all real words (i.e., correctly responding "word") and then averaging the accuracy for all non-words (i.e., correctly responding "non-word"). These two averages are then averaged together to give a final score for a given participant. The items used in this task are provided in Appendix C.

Procedure

Participants completed a masked-priming lexical decision task. A schematic of the timeline of events in trial is provided in Figure 2.1. All prime words were presented in lowercase font and all targets were presented in uppercase font. This minimized the effect of purely visual priming due to physical overlap of letters. Participants were instructed to decide if the target word was a real French word or not as quickly as possible, and that it was better to be fast and make mistakes than to be accurate and take their time. The target word remained on the screen until the participants gave their response, or for 5000 ms. Participants gave their responses with two adjacent buttons ("1" and "2") on the computer keyboard in front of them. The experiment was broken into four blocks to allow for short breaks. The entire experiment took approximately 15 minutes to complete.

Figure 2.1. Event order for each trial, Experiment 1



Stimuli

The real-word targets were all regular *–er* verbs (Class I) in their $1^{st}/3^{rd}$-person singular form, henceforth referred to as the stem form. This is the most common verb class in French. There were four conditions, each with 36 different target words, resulting in 144 real-word targets. Each target was created with two primes: a related prime and an unrelated prime. The four conditions are characterized by the relationship of primes and targets when the prime is related to the target: (i) identity (ID), where the prime and target are the exact same (stem) form, (ii) morphological (Morph), where the prime and target have the same verb root, but the prime is inflected with the 1^{st}-person plural affix *–ons*, (iii) orthographic (Orth), where the prime and target verb roots overlap in all letter except the final letter, and (iv) semantic (Sem) where the prime and target are synonyms (as rated by two native French speakers who did not participate in the study). All unrelated primes for each condition are unrelated orthographically and semantically. With the exception of the related primes for the identity condition, all primes were inflected with the 1^{st}-person plural *–ons* inflection. By having all primes (except related primes in the identity condition) appear with the *–ons* inflection, all conditions were made equal in necessity to decompose in order to receive facilitation in target recognition from stem activation.

As can be seen in Table 2.2, the regularly conjugated *–er* verbs have five orthographically distinct forms in the present tense conjugation paradigm, but only three phonologically distinct forms.

Table 2.2. French *–er* Verb Conjugation Paradigm (*donner* /dɔne/ ‘to give’)

1^{st}-sg	donne	/dɔn/	1^{st}-pl	donnons	/dɔnɔ̃/
2^{nd}-sg	donnes	/dɔn/	2^{nd}-pl	donnez	/dɔne/
3^{rd}-sg	donne	/dɔn/	3^{rd}-pl	donnent	/dɔn/

The stem form chosen for targets in the present study is in fact the 1^{st}/3^{rd}-person singular form because the true root of any given *–er* verb (e.g., *donn* for *donner*) is not a word in French, and thus cannot be used in a lexical decision task. Choosing the 1^{st}/3^{rd}-person singular to serve as the target allowed for orthographically minimal (*-e)* and phonologically null inflection. A similar decision for target words was made in Royle et al. (2012). As can be seen in Table 2.2 above, the 1^{st}-person plural form is orthographically and phonologically distinct from all other forms. Note that in addition to appearing as the present tense 1^{st}-person plural form (which requires an overt subject), this form can also appear as the *‘let’s’* imperative form when there is no subject present (e.g., *Dansons!,* ‘Let’s dance!’). The *–ons* inflection was chosen as the inflection for the primes for its ability to create forms of low surface frequency (as demonstrated in Table 2.3 below). Choosing an inflected form that creates low surface frequency forms was important for a study aiming to test decomposition because it has been proposed that inflected forms that are of a high enough surface frequency are stored in their whole-form, and are not decomposed (e.g., Alegre & Gordon, 1999; Baayen et al., 1997). Such a property is important in Experiment 1 because it allows for adjudication among *morphological* and *non-morphological* models of lexical processing. While some morphological models (dual-mechanism models) posit that some complex words are stored in their whole form (e.g., due to high surface frequency), all morphological models would predict complex forms of low surface frequency to be decomposed. By contrast, non-morphological models posit that complex forms are never decomposed into morphemes. By selecting stimuli of low surface frequency, Experiment 1 is in a strong position to test the predictions of morphological and non-morphological models. Finally, the *–ons* inflection has the additional property of being orthographically and phonologically distinct compared to the other conjugations in the *–er* verb paradigm, which may make it more perceptually salient to learners (e.g., Goldschneider & DeKeyser, 2001; discussed in greater detail in Chapter 4).

Example stimuli for each of the four conditions are provided in Table 2.3 below. This table also gives the mean length (in letters) and mean written surface frequency (per million words in the Lexique database, New et al., 2004). Note that the frequency data for inflected forms represents frequency per million when the form appeared in the present tense (with a subject) as well as in the *'let's'* imperative form (without a subject). The Lexique database does not include information to distinguish how the form appeared.

Table 2.3. Stimuli Mean (SD) Length (top) and Frequency (bottom)

Condition	Target		Related Prime		Unrelated Prime	
Morph	PENSE 'think'	5.25 (1.02); 22.48 (31.63)	pensons 'think'	7.25 (1.02) 0.86 (1.66)	brûlons 'burn'	7.25 (1.02) 0.28 (0.57)
Orth	BOUGE 'move'	5.03 (0.75); 27.44 (51.26)	boudons 'avoid'	7.11 (0.89) 0.59 (2.69)	tissons 'weave'	7.14 (0.87) 0.32 (0.56)
Sem	HURLE 'yell'	5.46 (0.89); 33.44 (44.52)	crions 'scream'	7.31 (1.01) 0.91 (2.14)	bayons 'gawk'	7.33 (0.96) 0.48 (1.57)
ID	DANSE 'dance'	5.25 (1.11); 23.98 (37.37)	danse 'dance'	5.25 (1.11) 23.98 (37.37)	prônons 'advocate'	7.25 (1.11) 0.65 (0.97)

In addition to the 144 real-word targets, the experiment also included 144 nonce targets. These targets were created to be orthographically and phonologically possible French words. They were matched in length (in letters) with the real-word targets, and were also created with 2 real-word primes each (also inflected with *–ons*). Real-word primes were used to ensure that the lexical status of the prime would not predict the lexical status of the target. A complete list of the real-word targets (with primes) and the nonce targets (with primes) is provided in Appendix D and Appendix E, respectively.

Analysis & Results

Accuracy of the lexical decision for each condition is given in Table 2.4.

Table 2.4. Accuracy by condition (percent)

Condition	L1 French	L2 French
Identity	91	83
Morphological	93	85
Orthographic	87	80
Semantic	93	82
Nonce	91	73

Nonce target items were not analyzed and were removed from the data set before analyzing accuracy data for the test items. Accuracy rates were analyzed to test if prime relatedness influenced accuracy at the lexical decision. The accuracy data were analyzed using a logistic regression model in R using the *lme4* package (Bates, Maechler, Bolker, & Walker, 2015). The R package *lmerTest* was used to provide *p*-values for models (Kuznetsova, Brockhoff, & Christensen, 2016). The model included accuracy (1 or 0) as the dependent variable, and Condition (ID, Morph, Orth, Sem), Relatedness (related, unrelated), Group (L1, L2), and Trial Order as fixed effects. For each categorical variable in the model, a single level is treated as the baseline to which the other levels of that variable are compared. In this model the baseline for Condition is Identity, the baseline for Relatedness is Unrelated, and the baseline for Group is L1 (native French speakers). Model fitting began by including all two-way and three-way interaction terms among the fixed categorical variables. Interaction terms were removed one at a time and the models were compared using a likelihood ratio test (LRT). If including interaction terms did not significantly improve the model, the simpler model was used. The final model included Condition, Relatedness, Group, Trial order, and the interaction term of Condition x Group. The R code structure for the best model for the accuracy data is provided below for reference.

```
glm(Accuracy ~ Condition + Related + Group + TrialOrder, family = binomial,
data= data)
```

The results of the logistic model show a simple effect of Condition for the Orthographic items (z (8639) = -3.478, $p < .001$), and a simple effect of Condition for Morphological items (z (8639) =

2.006, *p* =.045). The direction of the coefficient for the Orthographic items (negative) indicates that the items in the Orthographic condition had significantly lower accuracy compared to the baseline Identity items. The direction of the coefficients for the Morphological items (positive) indicates that these items had marginally higher accuracy compared to the Identity condition. These effects of condition are independent of whether the prime for a given item was related or unrelated to the target. The results of the accuracy model also show a significant simple effect of Group (z (8639) = -11.969, p <.001). This indicates that overall the non-native French speakers are less accurate than the native French speakers. The lack of interaction of any condition with prime relatedness indicates that there was no priming effect found in the accuracy data.

Reaction times were first cleaned by removing any trials where the lexical decision exceeded 3000 ms or was shorter than 300 ms. Mean reaction times were then calculated for each participant, and any trials with lexical decisions that were 2.5 standard deviations above or below that participant's mean were removed. This led to the removal of 3.4 % of the native speaker data, and 4.5% of the non-native speaker data. The analyses of reaction times only included trials where participants correctly identified the target as a real word. Excluding the trials with incorrect responses led to the removal of an additional 8.2% of the native speaker data and 16.8% of the non-native speaker data. A summary of mean reaction times (ms) is provided in Table 2.5 below. The priming effect (related – unrelated) is also provided.

Table 2.5. Mean reaction times (ms) and priming effects

Condition	Relatedness	L1 French	Priming (L1)	L2 French	Priming (L2)
Identity	Related	710	-29	766	-55
	Unrelated	739		821	
Morphology	Related	711	-27	770	-36
	Unrelated	738		806	
Orthographic	Related	724	-5	795	-7
	Unrelated	729		803	
Semantic	Related	737	+5	814	+7
	Unrelated	732		807	

To visualize the reaction time data, bar plots are provided in Figure 2.2 (L1 French) and Figure 2.3 (L2 French) below.

Figure 2.2. Reaction times, L1 French

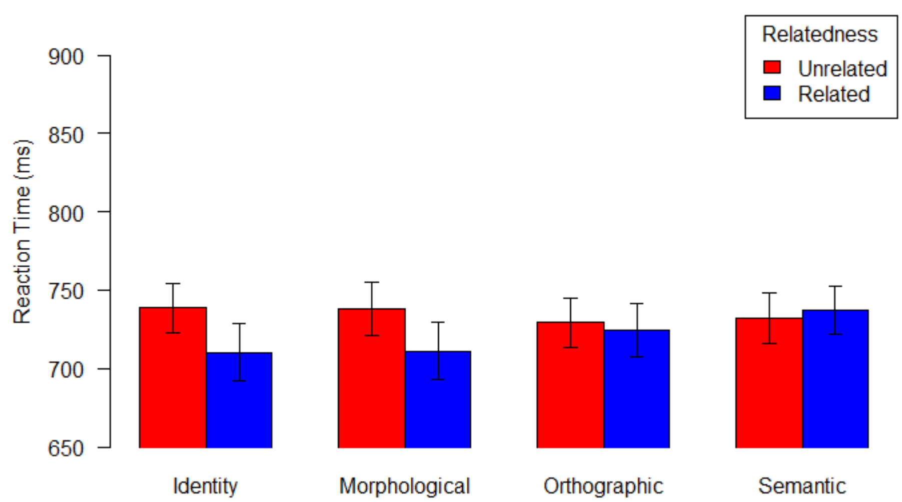
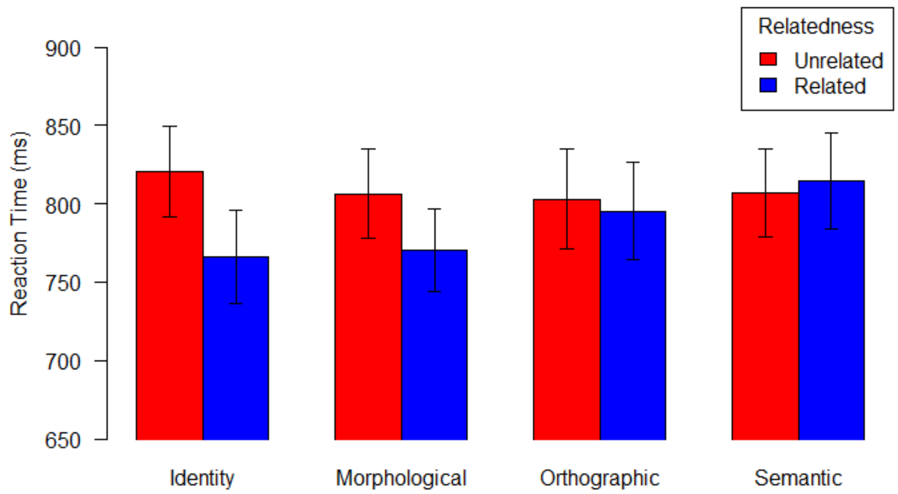


Figure 2.3. Reaction times, L2 French



Reaction time data were analyzed with linear mixed-effects models (lmer) using the *lme4* package in R (Bates, Maechler, Bolker, & Walker, 2015). The R package *lmerTest* was used to provide *p*-values for the models (Kuznetsova, Brockhoff, Christensen; 2016). Backwards stepwise model selection was carried out using the *LMERConvenienceFuncitons* package in R (Tremblay & Ransijn, 2015)[8]. Log-transformed reaction times were used as the dependent variable for all models testing for priming. To begin selection of the best and simplest model, the model was initially maximally fit with the fixed effects Condition, Relatedness, Group, log-transformed Target Frequency, and Trial order, along with all interaction terms (excluding any interaction terms with Trial Order). Additionally, the random intercepts of Item and Subject were included, as well as random slope of Group on the Item random intercept, and the random slope

[8] This function is unavailable for logistic models, like the models used to analyze accuracy. This function automatically executes the backwards stepwise comparisons done manually for the models for the accuracy data.

of log-transformed Target Frequency on the Subject random intercept. The R code structure for this initial model is provided below for reference.

```
lmer(logRT~Condition*Related*Group*logtargetfreq+TrialOrder+(1+Group|
Item)+(1+logtargetfreq|Subject),data)
```

This maximally fit model was reduced in a backwards stepwise manner in order to identify the simplest model that best fits the data (using the *bfFixefLMER_F.fnc*) function in the *LMERConvenienceFunctions* R package). This method of model selection removes effects terms one at a time and progressively compares simpler models to more complex ones using log-likelihood ratio tests. Terms that do no improve the fit of the model are removed, and the simplest model that best fits the data is returned. This method of model selection has been used in previous psycholinguistic and neurolinguistic studies (e.g., Newman et al, 2012; A. Tremblay & Tucker, 2011). The final model that best fit the data included fixed effects of Condition, Relatedness, log-transformed target frequency, and trial order, as well as the Condition x Relatedness interaction term. The R code structure of the final model is given below for reference.

```
lmer(logRT~Condition+Related+logtargetfreq+TrialOrder+Condition:Related+(1|
Item)+(1+logtargetfreq|Subject),data)
```

Similar to the accuracy model, each categorical variable must have a level that is considered a baseline for that variable. For the Condition variable the baseline is Identity, and for Relatedness the baseline is Unrelated. Other levels within a variable are compared to these baseline levels. The model additionally includes Subject and Item as random intercepts. Random intercepts for Item and Subject allow for each item and each subject to have separate slopes in the model, which allows the model to take by-item and by-subject variability into account. In addition to the fixed effects and random intercepts, the models were tested for the inclusion of random slopes. Random slopes were included when the model's AIC (Akaike Information Criterion) was lowered by at least a value of two (Wieling, 2015). The model best fit the data with the inclusion of the random slope of log-transformed target frequency for the Subject random intercept. The inclusion of random slopes allows for the fixed effects in the model to vary for each item or each subject (depending on to which random intercept they are added). The inclusion of the random slope of log-transformed Target Frequency on the Subject random intercept allows the model to account for the effect of frequency varying for each subject.

The results of this model reveal an effect of relatedness (t (7321) = -6.26, p < .001), indicating that in the Identity baseline condition, related primes elicit faster reaction times than unrelated primes. There is a significant effect of log-transformed Target Frequency (t (7321) = -7.752, p < .001), indicating that reaction times are faster overall to more frequent target words. There is also a significant effect of Trial Order (t (7321) = -6.017, p <.001), indicating that as the experiment progressed, participants got faster in the lexical decision times overall. There was an interaction of Condition x Relatedness for the Orthographic condition (t (7321) = 3.53, p < .001), indicating that the effect of Relatedness found in the baseline Identity condition is different in the Orthographic condition. There was also an interaction of Condition x Relatedness for the Semantic condition (t (7321) = 4.995, p <.001), indicating that the effect of Relatedness found in the baseline Identity condition is different in the Semantic condition. Importantly, the interaction for Condition x Relatedness for the Morphological condition did not reach or approach significance, indicating that the effect of Relatedness found in the baseline Identity condition was not different in the Morphological condition.

The interactions of Condition x Relatedness for the Orthographic and Semantic conditions were followed-up by doing separate analyses to test for the effect of Relatedness for items just in the Orthographic condition, and another analysis on items in the Semantic condition. The orthographic-only model used log-transformed reaction times as the dependent variable. The fixed effects where Relatedness (unrelated, related), log-transformed Target Frequency, and Trial Order. Item and Subject were included as random intercepts. Log-transformed Target Frequency was included as a random slope on the Subject random intercept. The results of the model investigating Orthographic items only reveal no effect of Relatedness (t (1742) = -1.231, p > .21). There is an effect of log-transformed Target Frequency (t (1742) = -5.103, p < .001), and an effect of Trial Order (t (1742) = -2.092, p <.05). This model shows that primes related to the target in orthography only do not offer any facilitation of target recognition compared to primes that are unrelated to the target. Additionally, reaction times were overall faster when the target was more frequent, and as the experiment progressed reaction times got faster overall.

A similar model was used to follow-up the interaction of Condition x Relatedness for the Semantic condition. The semantic-only model used log-transformed reaction times as the dependent variable. The fixed effects where Relatedness (unrelated, related), log-transformed

Target Frequency, and Trial Order. Item and Subject were included as random intercepts, and log-transformed Target Frequency was included as a random slope on the Subject random intercept. The results show no effect of relatedness (t (1847) = 0.554, p > .5). There was an effect of log-transformed Target Frequency (t (1847) = -4.033, p <.001), and an effect of Trial Order (t (1847) = -2.79, p < .01). The results of this model indicate that there is no facilitation in target recognition when the prime is semantically related to the target compared to when it is unrelated to the target. Additionally, reaction times are faster for more frequent targets, and reaction times decreased as the experiment progressed.

The above analyses included both native and non-native French speakers in the same model and found evidence of morphological priming that cannot be attributed to orthographic or semantic priming. Additionally, as there was no interaction with language group, this pattern of morphological processing is the same in both native and non-native French speakers. One potential point of criticism of this model is the uneven group sizes (35 native French speakers and 25 non-native French speakers). Unlike ANOVA analyses, linear mixed-effects models are generally robust to group size differences because they are able to apply weights to unbalanced groups, but to ensure that the difference in group sizes is not driving any effects found in the above model a follow up linear mixed-effects model was done with 25 native French speakers were selected to match the size of the non-native French group. The 25 native French speakers were selected by their participant number, with the middle 25 participant numbers being selected (i.e., participant 6 through participant 30).

The model with even group sizes used log-transformed reaction times as the dependent variable. Similar to the model with all 35 native French speakers described above, model selection was accomplished by starting with a maximally fit model. The maximally fit model was then progressively simplified by removing terms one at a time using the *bfFixefLMER_F.fnc* in the R package *LMERConvenienceFunctions*, which used log-likelihood ratio tests to find the simplest model that best fit the data. In the final model, the fixed effects were Condition (ID, Morph, Orth, Sem), Relatedness (unrelated, related), log-transformed Target Frequency, and Trial Order. The interaction term of Condition x Relatedness was also included. Item and Subject were included as random intercepts, and log-transformed Target Frequency was included as a random slope on the Subject random intercept. The baseline levels were the same as those used in the models above (Identity for Condition, and Unrelated for Relatedness). The R code structure for the model is provided below for reference.

```
lmer(logRT ~ Condition + Related + logtargetfreq + TrialOrder +
(1|Item) + (1+logtargetfreq|Subject) + Condition:Related,data2)
```

The results of the model reveal a significant effect of Relatedness (t (6032) = -5.505, p < .001), a significant effect of log-transformed target frequency (t (6032) = -7.437, p < .001), a significant effect of trial order (t (6032) = -6.956, p < .001), and significant interactions of Condition x Relatedness for both the Orthographic condition (t (6032) = 2.88, p < .01) and the Semantic condition (t (6032) = 4.369, p < .001). The results of this model show the exact same patterns as the model above that included all 35 native French speakers. The results of this model reveal that in the Identity condition, reaction times are faster when the prime is related to the target compared to when the prime is unrelated to the target, but this pattern is different in the

Orthographic and Semantic conditions. The lack of interaction of Condition x Relatedness for the Morphological condition indicates that the effect of Relatedness in the Identity condition does not differ in the Morphological condition. Additionally, reaction times are faster for targets that have a higher frequency, and reaction times also decrease as the experiment progresses. When backwards fitting the model Group was removed (as a simple effect and as an interaction term) because it did not improve the model, which indicates that the L1 and L2 groups do not differ in this task.

As was done in the above model with all 35 native French speakers, the interactions of Condition x Relatedness for the Orthographic and Semantic conditions were further investigated by running separate analyses for each condition to test for an effect of relatedness. The first follow-up model tested just the Orthographic items. The model included Relatedness, log-transformed Target Frequency, and Trial Order as fixed effects. Item and Subject were included as random intercepts, and log-transformed Target Frequency was included as random a slope (on the Subject random intercept). The results of the Orthographic model show no effect of Relatedness (t (1384) = -1.59, p >.1), but there was an effect of log-transformed target frequency (t (1384) = -5.08), p <.001), and an effect of trial order (t (1384) = -2.91, p <.01). The results indicate that the orthographically related primes did not offer any facilitation in target recognition compared to unrelated primes, and this was true for both native and non-native French speakers. A model with the same parameters was fit for the Semantic condition. The results of the semantic-only model reveal no effect of Relatedness (t (1465) = 0.48, p >.6). There was an effect of log-transformed Target Frequency (t (1465) = -3.58, p < .001), and an effect of Trial Order (t (1465) = -2.80, p <.01). The results of this model show that the semantically related primes offer no facilitation in target recognition compared to unrelated primes, and this is true for both native and non-native French speakers.

The results of this model on a subset of the native French speakers along with 25 non-native French speakers showed the same results as the model including all 35 native French speakers.

Non-native French group only

The above analyses suggest that, like native French speakers, non-native French speakers processing morphologically complex words by accessing a morphological level of representation in their mental lexicon. Both groups showed significant and equivalent facilitation in target recognition when a target was primed by either an identical word or by a morphologically related word. Importantly, these priming effects cannot be attributed to the fact that identical and morphologically related primes share orthography and semantic information with their targets. There was no facilitation of target recognition when the prime was either orthographically or semantically related to the target, indicating that these properties are not driving the facilitation in the identity and morphology conditions. These findings go against predictions made by Clahsen and colleagues who argue that non-native speakers process complex words in a qualitatively different way from native speakers. Ullman's predictions regarding non-native processing of morphologically complex words are that it is possible to achieve native-like processing (by breaking into a grammar that includes morphological structure), but this will only happen at sufficiently high proficiency and experience with the non-native language. In order to test Ullman's hypothesis of a qualitative shift from non-native-like to native-like processing, a separate set of analyses were conducted on the non-native French group to investigate what role, if any, proficiency plays in a non-native speaker's ability to process complex words at a morphological level.

The non-native French speakers completed two proficiency measures (a cloze test and a LexTale-inspired lexical decision task). As both tests aim to measure the same overall knowledge, it is unsurprising that participants' scores for each test are highly correlated ($r = 0.66$, $p<.001$). A continuous variable named "Proficiency" was created by averaging participants score on the cloze test (i.e., their score divided by 45) and their score on the LexTale-inspired task (which is already in proportion form). The resulting "Proficiency" score was then log-transformed, normalizing the distribution of the scores. There was one participant who did not complete either the cloze score or the LexTale-inspired task because she was involved in the creation of an internet-based implementation of the two proficiency tasks, and consequently had exposure to the correct answers for each. A linear model was fit with all other participants' language background variables (age of first exposure, years of French instruction, percent weekly use of French, and months of immersion) as predictors of their cloze test scores. A similar model was then used to predict score on the LexTale task. The coefficients of this model along with this particular participant's language background information were used to predict her cloze test score and her LexTale score. As was done with the other participants' scores, the two scores were then averaged to create a "Proficiency" score, which was then log-transformed to be used in the analyses.

Familiarity rating

In addition to the main experiment, the language background questionnaire, and the two proficiency measures, the non-native French speakers completed a familiarity task where they indicated how familiar they were with test items, using a scale of 1 to 7 (where 1 = "I did not know this was a French word", and 7 = "I know and use this word frequently"). The participants rated their familiarity with all target words that appeared in the masked-priming task, as well as all related prime words (i.e., the *–ons* inflected forms). This set of data was collected to get a sense of how familiar participants were with each item, and potentially use familiarity as a predictor in the models analyzing reaction times.

A number of the variables that could potentially be used in the reaction time analyses must first be tested for collinearity to avoid including multiple correlated variables as predictors in the reaction time analyses. The variables tested for collinearity were proficiency (i.e., the averaged cloze score and LexTale-inspired task score), familiarity with target words, and log-transformed target frequency. To test if familiarity of targets is correlated with proficiency, average familiarity ratings to target words were calculated for each participant. There was a significant correlation between participants' proficiency and their mean familiarity with target items (r = .46, p <.02), indicating that as proficiency increases, overall familiarity with the target items increases. Next, target familiarity and (log-transformed) target frequency were tested for collinearity. For each target item, the average familiarity rating was calculated. Average familiarity for each target and that target's log-transformed target frequency were then correlated. This test revealed a significant correlation (r = .61, p < .001), indicating that as frequency increases, overall familiarity increases. Given that the familiarity ratings provided by the participants correlate with both proficiency and log-transformed target frequency, the analyses on the reaction times cannot include all three variables as predictors.

To decide which variables allow for the best model fit, two linear mixed-effects models were created and compared. The models were fit using the *lmer* function in the R package *lme4*. The first model was maximally fit to include Condition, Relatedness, log-transformed Proficiency, log-transformed Target Frequency, and Trial Order (along with all interaction terms) as fixed effects. Item and Subject were included as random intercepts, and log-transformed Target Frequency was included as a random slope for the Subject random intercept. This maximally fit model was progressively simplified by removing fixed effect terms one at a time and comparing simpler models to more complex models by means of log-likelihood ratio tests (*LMERConvenienceFunctions* R package) to arrive at the simplest model that best fits the data. The best model identified through this process included Condition, Relatedness, log-transformed Target Frequency, and Trial Order as predictors, as well as the interaction of Condition x Relatedness. The model's Akaike Information Criterion (AIC) value was extracted from this model using the *glance* function in the *broom* R package (Robinson et al., 2015) as a measurement of its quality as a model; this value will be used to compare the two models.

The second model was initially maximally fit with Condition, Relatedness, Familiarity, and Trial Order (and all interaction terms except those including Trial Order) as fixed effects. Item and Subject were included as random intercepts, and log-transformed Target Frequency was included as a random slope for the Subject random intercept. This maximally fit model was then progressively simplified by means of log-likelihood ratio tests (as described above). The best model identified included Condition, Relatedness, Familiarity, and Trial order, as well as four interaction terms: Condition x Relatedness, Condition x Familiarity, Relatedness x Familiarity, and Condition x Relatedness x Familiarity. This model's AIC was extracted for comparison.

The AIC for the first model (with log-transformed Target Frequency) was 127.75; the AIC for the second model (with Familiarity) was 164.75. In terms of evaluating model quality, lower AIC indicates a better quality model, which leads to the conclusion that the model including log-transformed Target Frequency in place of target Familiarity allows for a better model. Only the results of this selected model will be discussed below. The R code structure of the final model for the non-native French group is provided below for reference.

```
lmer(logRT~ Condition + Related + logtargetfreq + TrialOrder +
Condition:Related + (1|Item) + (1+logtargetfreq|Subject),data)
```

The results of this model reveal a significant effect of Relatedness (t (2854) = -4.783, p<.001), a significant effect of log-transformed Target Frequency (t (2854) = -5.236, p<.001), and a significant effect of Trial Order (t (2854) = -4.892, p<.001). Additionally, there was an interaction of Condition x Relatedness for the Orthography condition (t (2854) = 2.653, p<.01), as well as an interaction of Condition x Related for the Semantic condition (t (2854) = 3.494, p<.001). These results indicate that in the baseline Identity condition, related primes elicit significantly faster reaction times than unrelated primes. Additionally, more frequent targets overall have faster reaction times, and as the experiment continues, participants' reaction times get faster overall. The interactions indicate that whereas related primes offer facilitation in the Identity condition, this pattern is different in the Orthography and Semantic conditions. The lack of interaction of Condition x Relatedness for the Morphology condition indicates that the pattern of facilitation from related primes in the baseline Identity condition does not differ in the Morphological condition. Importantly, proficiency was not included in this model because it was not a significant predictor of reaction times and including it did not improve the model's fit of the data. This means that proficiency does not influence overall reaction times in this task, nor does it modulate priming effects.

As was done in the analyses with native and non-native French speakers together (above), follow-up models were used to investigate the interaction of Condition x Relatedness for the Orthographic and Semantic items (separately). The model investigating Orthographic items only used log-transformed reaction times as the dependent variable. Relatedness, log-transformed Target Frequency, and Trial Order were included as fixed effects. Item and Subject were included as random intercepts, with log-transformed Target Frequency included as a random slope for the Subject random intercept. The results of this model reveal only a significant effect of log-transformed Target Frequency (t (683) = -2.940, p<.01), indicating that more frequent target items elicited faster reaction times overall (independent of prime relatedness). There was no effect of Relatedness (p>.4), indicating that the orthographically related primes offered no facilitation in target recognition compared to unrelated primes. There was also no effect of Trial Order (p>.2). The model for Semantic items only used log-transformed reaction times as the dependent variable. Relatedness, log-transformed Target Frequency, and Trial Order were included as fixed effects. Item and Subject were included as random intercepts, with log-transformed Target Frequency included as a random slope for the Subject random intercept. The results of the Semantic model revealed a significant effect of log-transformed Target Frequency (t (712) = -3.237, p<.01), as well as a significant effect of Trial Order (t (712) = -2.067, p<.05), indicating that more frequent words elicited faster reaction times overall, and reaction times decreased overall as the experiment progressed. There was no effect of Relatedness (p>.9), indicating that semantically related primes offered no facilitation of target recognition compared to unrelated primes.

While further investigation of the effect of Relatedness for the Morphological condition is not theoretically justified due to the lack of interaction of Condition x Relatedness for the Morphological condition in the non-native French model, it is of interest to the present study to fully investigate how morphologically related primes influence target recognition for non-native French speakers. A follow-up model is used to analyze items in the Morphological condition only. Like the follow-up models for the Orthographic and Semantic items (above), the Morphological model used Relatedness, log-transformed Target Frequency, and Trial Order as fixed effects to predict log-transformed reaction times. The random effect structure was the same as was used in the Orthographic and Semantic models. The results of the Morphological model reveal a significant effect of Relatedness (t (735) = -2.802, p =.005), which is evaluated as significant even with a conservative Bonferroni correction to the alpha due to multiple comparisons. The results of the model also reveal a significant effect of log-transformed Target Frequency (t (735) = -3.915, p<.001), and a significant effect of Trial Order (t (735) = -4.469,

p<.001). The results of this Morphological model further demonstrate that morphologically related primes significantly facilitate target recognition compared to unrelated primes.

Discussion *Experiment 1*

Experiment 1 aimed to test if native and non-native French speakers process morphologically complex words in a qualitatively similar way. The analyses that included native and non-native French speakers together indicate that these two groups of French speakers process morphologically complex words in qualitatively similar ways. More specifically, both groups show evidence of decomposing inflected forms into stem and affix, and accessing a morphological level of representation in the lexicon. There was significant and equivalent facilitation in target recognition when the prime word was either identical to the target or morphologically related to the target (i.e., *full priming*). This provides evidence that the morphological prime was decomposed into its morphological constituents, and the verb stem was activated in the lexicon, leading to facilitation in target recognition that was equal to the facilitation offered from a prime being presented in the stem form. Additionally, there was no facilitation of target recognition offered by either orthographically related or semantically related primes compared to unrelated primes. The lack of priming in these two conditions indicates that the priming found in the identity and morphological conditions cannot be explained by the fact that the morphological primes overlapped in orthography and semantic information with the target word, suggesting the source of the facilitation is morphological in nature. The findings of Experiment 1 are in line with the findings of previous studies that used different priming methodologies to test for evidence of morphological processing in adult learners (e.g., Basnight-Brown et al., 2007; Feldman et al., 2010, Coughlin & Tremblay, 2015).

Experiment 1 also aimed to investigate how proficiency in the L2 may modulate a non-native speaker's ability to process inflectional morphology in a native-like way. Clahsen and colleagues predicted that independent of an adult leaner's proficiency in the L2, native-like processing is not predicted to be possible because the grammar is believed to be deficient and lack morphological structure to inflected words (e.g., Clahsen et al., 2010). The results of Experiment 1 are in direct opposition to this claim. The French learners in Experiment 1 show evidence of a native-like sensitivity to the morphological structure of inflected words. Unlike the claims from Clahsen, Ullman predicted that lower-level learners are unable to process morphological information in a native-like way, but at sufficiently high proficiency a learner will gain access to the brain mechanisms responsible for morphological decomposition. The analyses on non-native French speakers alone in Experiment 1 revealed that proficiency does not reliably account for any variability in the reaction time data, indicating that all participants in the study, regardless of their French proficiency, showed evidence of decomposing inflected words. The findings in Experiment 1 are in partial agreement with Ullman's predictions in that the French learners did show evidence of decomposing morphologically structured words into morphemes, indicating that they have access to the brain mechanisms responsible for morphological decomposition. However, the results of Experiment 1 are in disagreement with Ullman's predictions in that there is no evidence that sufficient proficiency in French is what allowed the learners to process morphological information in a native-like way. That is, Ullman's prediction of a qualitative shift was not borne out in the results of Experiment 1. It is possible that the French learners do not show proficiency effects (as predicted by Ullman) because at the time of testing they had already gone through the predicted qualitative shift from whole-word storage to decomposition. This possibility is, however, unlikely. The participants in Experiment 1 had a wide range of proficiency in French (low-level to high-level), with the mean proficiency rating at a level that can qualitatively be described as mid-to-high-intermediate. Ullman's predictions are phrased in a way that indicate a very high level of proficiency may be necessary to gain access to the decomposition routine, but this is not an accurate description of the average participant in Experiment 1. A number of Ullman's studies investigating morphological processing in L2 Spanish by native English speakers (Babcock et al., 2012; Bowden et al., 2010) did not find evidence of morphological processing in mid-to-advanced learners. The results of these studies were discussed as evidence that a very high level of proficiency is necessary before learners will go through a qualitative shift that makes decomposition available as a processing routine. It is thus unlikely that the participants in Experiment 1 already went through the predicted proficiency-driven qualitative shift.

While the results of Experiment 1 do indeed differ from a number of studies aiming to test if morphological decomposition is possible for inflected forms in a late-learned L2, the findings are similar to some previous studies that also found evidence of morphological processing in a late-learned language. In a recent study, Foote (2015) also used a masked-priming lexical decision task to study how native and non-native speakers of Spanish processed verbal and adjectival inflectional morphology (e.g., *cante-CANTA*,'s/he sing-S/HE SINGS'; *tonto-TONTA*, 'silly $_{\text{MASC}}$-SILLY $_{\text{FEM}}$'). Foote's study included five prime-target word pairs (identity, morphological, orthographic, semantic, and unrelated), which put her study in a similar position of being able to test if any morphological priming can be attributed to the shared orthography and semantics between morphologically related words. Similar to the results in Experiment 1, Foote found no difference between native and non-native Spanish speakers in their processing of inflections, and concluded that both native and non-native Spanish speakers were able to show evidence of morphological decomposition for inflected words. Foote's analyses also included proficiency as a continuous variable, and interestingly, her findings found no interaction of proficiency and priming. That is, her study also suggests that even learners of lower proficiency levels are able to show evidence of decomposing inflected words. In studies investigating native-like processing of a given linguistic domain, native-like processing abilities are typically only found at high levels of proficiency (e.g., Rossi et al., 2006 in morphosyntactic agreement). The findings in Experiment 1 and in Foote (2015) that indicate native-like processing ability to decompose complex words independent of proficiency is thus quite surprising.

When comparing the findings in Experiment 1 to the many previous masked priming lexical decision tasks that failed to find evidence of decomposition of inflected forms (e.g., Silva & Clahsen, 2008; Neubauer & Clahsen, 2009; Kirkici & Clahsen, 2013), it is not easy to pinpoint a single difference in the studies that could clearly explain why the conclusions differ so drastically, though there are a number of points to consider. One possible reason Experiment 1 was able to find evidence of decomposition, when previous similar studies did not, could be a question of power. Experiment 1 included 36 target items per condition, which meant that every participant saw 18 trials where the prime was related to the target, and 18 trials where the prime was unrelated to the target, for a given condition. This gives the experiment significant power compared to the 7 items per condition per participant in Silva & Clahsen (2008). However, this difference cannot fully explain the difference in findings because in Foote's (2015) study on Spanish, participants only saw 6 items per condition, yet her results demonstrated *full* priming effects for the learners.

Another possible explanation of why Experiment 1 allowed for such different conclusions compared to previous work by Clahsen and colleagues may be due to the inflection that was used to test for morphological sensitivity. In Experiment 1, morphologically complex words were inflected with the first-person plural inflection *–ons*. This inflection was chosen because when a word takes this inflection, the surface frequency of the inflected form is very low (see Table 2.3 above for mean frequencies). Low surface-form frequency is critical for studies testing for decomposition because it has been proposed by some researchers that inflected forms of high enough surface frequency will not be decomposed by native speakers (e.g., Alegre & Gordon, 1999). Silva & Clahsen (2008) did not provide the mean surface-frequency for the morphological primes, but in Kirkici & Clahsen (2013) the inflected prime words have a reported mean frequency of 63.2 (per million words, Middle East Technical University Turkish corpus; Say, Zeyrek, Oflazer & Özge, 2002). In Foote's (2015) study, the inflected verb primes had a mean surface-form frequency of 10.72 (per million words, LEXESP Spanish corpus, Sebastián Gallés et al., 2000). In Experiment 1, the mean surface-from frequency was 7.25 (per million words, Lexique French database; New et al. 2001). It is difficult to compare frequencies across languages and corpora, but it may be the case that the inflected items in Experiment 1 were of significantly lower surface-form frequency than the items used in previous studies that did not find evidence of morphological decomposition. It may be the case that the carefully chosen inflection and test items in Experiment 1 placed the task in an ideal position to test if learners are able to decompose inflected forms.

While the behavioral results provided by Experiment 1 shed considerable light on our understanding of the language processing mechanisms available in a non-native language, the reaction times in a lexical decision task are unable to inform our understanding of the time-course of lexical access, and how native and non-native speakers may differ in the neurophysiological components of lexical access. Experiment 2 (below) incorporates electroencephalographic (EEG) recording as a means of investigating if morphological decomposition and lexical access unfold over time in a similar way in native and non-native speakers of French.

Chapter 3: Experiment 2

Introduction

The use of behavioral tasks such as masked priming lexical decision has provided a tremendous amount of insight into how people process morphologically complex words. While such tasks allow researchers to answer many interesting questions about what types of linguistic relationships between primes and targets will influence behavioral responses, the reaction time data in these behavioral studies are unable to shed light on the linguistic processes taking place at the neurophysiological level. Reaction times in behavioral studies capture the final product of processing, and consequently are unable to shed light on how lexical processing unfolds over time. One measure that is able to capture moment-by-moment activity in the brain is EEG recordings. Over the past decade a number of studies have made use of electroencephalographic (EEG) technology to examine how lexical access unfolds over time for morphologically complex words. Experiment 2 uses EEG data to investigate if native and non-native French speakers arrive at the same morphological priming effect (as seen in Experiment 1) via the same processing routes in the brain.

Event-Related Potentials

In EEG experiments participants wear a cap with an array of embedded electrodes that record the electrical activity on the scalp. During an experiment, the recording of electrical activity is time-locked to the presentation of a particular stimulus (e.g., the presentation of a target word). The electrical signal is sent to an amplifier system, and the responses to all items in a given condition are averaged together to yield an *event-related potential* (ERP). Incorporating EEG recordings in a linguistic experiment provides a number of key insights into how language is processed in the brain. First of all, EEG data can capture *whether* a brain response is elicited for a certain type of linguistic stimuli. Additionally, because EEG is able to capture millisecond-by-millisecond changes in electrical activity (i.e., it has excellent temporal resolution), it is able to capture *when* a certain brain response takes places. Finally, EEG data can shed light on the qualitative nature of a brain response to linguistic stimuli. Specifically, EEG responses are characterized by properties such as timing, amplitude, and the topography of the response across the scalp. Different EEG responses have been associated with qualitatively different aspects of language processing, as discussed below for morphological processing

In the past decade, many researchers have used EEG recordings to better understand the time-course of lexical access in priming studies. In these studies, two key EEG components have been found to be influenced by the relationship between prime and target words: The N250 and the N400. Importantly, these two components show sensitivities to qualitatively different properties in the stimuli.

The N250 is a negative-going waveform that peaks around 250 ms after the onset of the target word. It is typically found along the midline of the scalp in addition to left anterior electrode sites. The N250 reflects early stages in lexical access when the stimulus is presented visually, and is influenced by orthography. Previous masked priming studies have found that its amplitude (in the negative direction) is greatest when the prime and target words are orthographically distinct, and the amplitude is smallest when the prime and target words are identical (i.e., repetition priming). This EEG component is believed to reflect the processing stages before lexical activation due the fact that real words and nonce words elicit similar responses (e.g., Holcomb & Grainger, 2006).

The N400 is a negative-going waveform that peaks around 400 ms after the onset of the target word. It is typically found in central-posterior sites on the scalp and is believed to reflect the processing demands of semantic integration and lexical access (see Kaan, 2007 for review). In masked priming studies the N400 amplitude is influenced by shared morphology between prime and target. Its amplitude is greatest (in the negative direction) when prime and target words are unrelated, and its amplitude is smallest when prime and target are identical. Prime-target pairs that share root morphemes have also been shown to reduce the amplitude, suggesting it is sensitive to shared morphology (e.g., Domínguez, de Vega, & Barber, 2004).

The fact that these two EEG components (N250 and N400) capture different aspects of lexical processing, and one of them is sensitive to morphological overlap, makes them ideal components to investigate in the present study which aims to examine the time-course of lexical processing in the L2, and test for morphological priming that is distinct from orthographic priming.

ERP responses from morphological processing

A study by Holcomb & Grainger (2006) demonstrated the different sensitivities captured by the N250 and N400 components. Their masked priming task included prime-target pairs that were either complete repetitions (e.g., *table-TABLE*), partial repetitions (e.g., *teble-TABLE*), or unrelated pairs (e.g., *mouth-TABLE*). The EEG results showed that when the prime and target shared orthography, the negativity in the N250 time-window was significantly and equivalently attenuated compared to when the prime was unrelated to the target. The negativity in the N400 time-window only showed significant attenuation for complete repetitions. These findings are of particular interest for the present study in that the stimuli included full repetition (identity) primes. Given that the present study aims to compare morphological priming to identity priming as a means of testing for morphological decomposition, it is important to understand how identity primes affect the negativities in the N250 and N400 time-windows. Holcomb & Grainger's data suggest that identity primes have similar influence on the N250 and the N400. Additionally, the finding that identity primes and orthographically related prime similarly affect the N250 component offer further support that the N250 is sensitive to orthography during the pre-lexical stages of processing whereas the N400 is sensitive to lexical properties and repetition. While Holcomb & Grainger (2006) do not directly test for the ERP responses elicited by shared morphology between prime and target, it allowed for other studies to make predictions about how morphological decomposition may influence the N250 and N400 components.

Many of the recent studies that have incorporated EEG recording into masked priming lexical decision tasks have investigated how native English speakers process derived morphologically complex words (e.g., *farmer*), and words that appear to have the same morphological structure (e.g., *corner*) but are in fact morphologically simple (e.g., Lavric, Clapp, & Rastle, 2007; Morris et al. 2007, 2008). For example, Lavric et al. (2007) used a masked priming lexical decision task while recording EEG data from native English speakers where the stimuli included morphologically complex words priming their stem target (e.g., *farmer-FARM*), words with the appearance of morphological structure but lacking semantic transparency between prime and target (e.g., *corner-CORN*), and words that overlapped only in orthography (e.g., *brothel-BROTH*). There were also items where the prime and target were completely unrelated. The experiment includes items such as *corner-CORN* because they are able to offer interesting insight into the types of linguistic information that initiate morphological decomposition. Priming from such items suggests that morphological decomposition processes may be initiated simply by the orthographic appearance of morphological structure (e.g., *corner* is exhaustively segmentable into *corn* and *–er*, which are both morphemes in English). Additionally, finding robust priming from prime-target pairs that lack semantic transparency between words (like *corner-CORN*) suggests that semantic overlap between prime and target does not affect the morphological decomposition process in a masked priming task. Of relevance to the present study, the EEG results in Lavric et al. (2007) showed an attenuation of the N250 when the prime and target shared orthography, and this attenuation was equal for the three different test conditions where primes and targets overlap in orthography (i.e., *farmer, corner, brothel*). This finding indicates that early stages of lexical access are sensitive to the orthographic form of words. The overlap of letters between the prime and target influences this stage of lexical processing. Lavric et al.'s results revealed that the N400 component is sensitive to a different type of overlap between prime and target compared to the N250, namely the apparent presence of morphology. The N400 was attenuated for prime-target pairs like *farmer-FARM* and *corner-CORN*, but not for pairs that shared only orthography (such as *brothel-BROTH*). These findings provide insight on two aspects of lexical processing in a masked priming context. First, the finding that the orthographic appearance of morphological structure is sufficient to initiate the morphological decomposition procedure, and this happens very quickly (within 400 ms). Second, these findings indicate that morphological decomposition and morphological activation can happen independent of access to semantic information. The finding that semantically unrelated words like *corner-CORN* elicit the same brain response as semantically related words like *farmer-FARM* indicates that semantic overlap between words does not influence the morphological decomposition procedure. Such findings demonstrate that constituent morphemes are activated in the lexicon even when the individual morphemes are not semantically related to the whole word. Morris et al. (2007, 2008) also tested morphologically complex words that were either semantically transparent or semantically opaque and found similar results as Lavric et al. (2007). In the Morris et al. studies, the N250 and N400 were significantly and equally attenuated by morphologically related words, independent of whether the morphological stem was semantically related to the whole word. The findings in this study are important to the present study in that they demonstrate a qualitative difference in the two EEG components of interest. The N250 is affected by shared orthography between prime and target, whereas the N400 is affected by shared morphology.

While many of the previous EEG studies that made use of masked priming were investigating derived complex forms (e.g., Morris et al. 2007, 2008), Morris & Stockall (2012) investigated morphological priming with inflected forms. This masked priming study included English past tense primes and stem targets (e.g., *walked-walk*), in addition to identity primes with verb stems (e.g., *walk-walk*), orthographic primes, and unrelated primes[9]. The morphological primes included an additional manipulation of regularity (regular and irregular inflected past tense verbs).

[9] Morris & Stockall (2012) did not provide examples of orthographically related prime-target pairs

Similar to previous studies, the negativity in the N400 time-window was attenuated only by prime-target pairs that share morphology (i.e., identity and morphological conditions). The N250 component was also only attenuated by morphologically related primes. The N250 component in the orthographic prime condition did not differ from the unrelated condition. The authors use these findings to argue that the presentation of inflected words quickly leads to the activation of a morphological representation in the lexicon. It is interesting to the note the different findings for the N250 component in this study compared to the findings in other masked priming EEG studies that found N250 attenuation from orthographically related primes. However, it is not uncommon for masked priming EEG studies to fail to find an influence of orthographic overlap for the N250 component. Morris et al. (2007, 2008) also found no attenuation of the N250 component when primes overlapped in orthography only with targets (e.g., *scandal-scan*). While the influence of orthographic priming on the N250 component may be varied across studies, the pattern of shared morphology influencing the N400 in native speakers is a common finding across many studies.

A recent study by Royle et al. (2012) used a masked priming lexical decision task during EEG recording to investigate how native French speakers process inflected French verbs. The test inflection was the third-person singular imperfect past tense inflection *–ait*. The stimuli in this study were prime-target pairs that were either morphologically related (e.g., *cassait-CASSE*, 'broke-BREAK'), orthographically related (*cassis-CASSE*, 'blackcurrant-BREAK'), semantically related (*brise-CASSE*, 'break-BREAK'), or unrelated (*moque-CASSE*, 'mock-BREAK'). The stimuli in their study were carefully designed so that the morphological primes and the orthographic primes had equal orthographic overlap. For example, for the target word

CASSE, the morphological prime (*cassait*) overlapped in the first four letters with the target (i.e., the verb stem). Similarly, the orthographic prime (*cassis*) also overlapped in the first four letters with the target (i.e., the stem was embedded in the orthographic prime). This feature of the stimuli allowed the authors to tease apart morphological priming from orthographic priming in that in both conditions the verb stem is orthographically present in the prime, but only one condition is morphologically structured.

The EEG components of interest in the study were again the N250 and the N400. The EEG data showed that the negativity in N250 time-window was significantly attenuated when the prime and target words overlapped in orthography. The negativity in the N400 time-window, however, was attenuated only when the prime and target shared morphology. The authors concluded that early stages of lexical access are sensitive to the orthographic form of a word, but very quickly (within 400 ms) a morphological unit of representation is activated in the lexicon. There was no priming effect from semantic primes in any time-window, which is consistent with the claim that masked priming tasks prevent semantic priming effects.

Experiment 2

Experiment 2 used a masked priming lexical decision task during EEG recording to investigate how non-native French speakers process inflected forms, and whether it is qualitatively similar to how native French speakers process inflected forms. Additionally, a wide range of L2 French proficiency levels were tested, which allowed Experiment 2 to investigate if proficiency in the L2 influences how inflection is processed. The masked priming lexical decision task is the same as Experiment 1, but incorporating EEG data will shed light on the time-course of morphological processing in a language learned after childhood. As in Experiment 1, Experiment 2 includes four target types (identity, morphological, orthographic, and semantic), with each target being preceded by either a related or unrelated prime word.

The previous studies investigating morphological processing by using masked priming tasks during EEG recording provide interesting insight into the stages of lexical processing, and how morphologically complex words are accessed and represented in the lexicon. In many previous studies, when the prime and target words overlap in orthography, the N250 component is significantly less negative than when the prime and target are orthographically unrelated. Such findings indicate that the early stages of visual lexical processing are sensitive to the orthographic form of the words. Given these findings, for native French speakers it is predicted for Experiment 2 that the N250 component will be significantly attenuated (less negative) when the prime and target overlap orthographically (in the identity, morphological, and orthographic condition). If non-native French speakers are equally sensitive to orthography in the early stages of lexical access, they are predicted to show similar attenuation of the N250 in the conditions where prime and target overlap orthographically.

The studies discussed above show consistent findings for the N400 component. When the prime and target words are (or appear) morphologically related, the N400 is significantly attenuated than when the prime and target are morphologically unrelated. The influence of morphological overlap on the N400 has been found for both derived and inflected forms, but specifically of interest to the present study is the effect of shared morphology between inflected verbs and their stem (as in Morris & Stockall, 2012, and Royle et al., 2012). The previous findings also allow for clear predictions about trials where the prime and target share morphology (i.e., identity and morphological conditions). For the native French speakers, it is predicted that when the prime-target pairs share morphology, the negativity in the N400 time-window will be significantly less negative compared to when the prime-target pairs are unrelated. Importantly, the attenuation that is found in instances of shared morphology should be significantly greater than any attenuation found from orthographic or semantic primes. The semantic primes are predicted not to attenuate the N250 or N400 components due to the fact that the primes are masked, and the very brief presentation of primes is believed to block semantic priming between prime and target (e.g., Royle et al., 2012).

To my knowledge, no study has investigated morphological decomposition at the brain level in late learners of a second language, so previous studies cannot inform predictions about how the EEG data will pattern for the L2 learners. However, if learners of French are able to decompose morphologically complex words into stem and affix, and access a morphological level of representation in the lexicon (as was found in Experiment 1, above), it is predicted that the negativity in the N400 time-window will be attenuated when the prime-target pairs share morphology (i.e., identity and morphological primes) compared to unrelated primes. Importantly, the attenuation from shared morphology should be significantly greater than any attenuation found when the prime-target pairs are orthographically or semantically related. If Ullman's predictions are correct, and a high level of proficiency must be attained before learners are able to decompose morphologically complex words, then it is predicted that the lower level learners in Experiment 2 will show qualitatively different brain responses for the morphological condition compared to the native French speakers. More specifically, the morphological primes should not pattern like the identity primes for the learners at lower proficiency. Additionally, if Ullman is correct in his predictions about proficiency driving native-like morphological processing, the learners at high levels of French proficiency should pattern like native speakers by showing similar attenuation of the N400 when the prime is identical or morphologically related to the target.

Participants

Twenty-seven right-handed native French speakers (29 females) participated in the study (age range 19-41 years; mean 22.2 years). Participants were paid for their participation. Before beginning the main experiment, participants filled out the Edinburgh handedness questionnaire (Oldfield, 1971) to ensure they were right-handed, as well as a short language background questionnaire where they provided biographical information pertaining to their language experiences (see Appendix A). Participants grew up in either Québec, Canada (n=25) or France (n=2). All participants grew up in households where French was the only spoken language and all participants were currently enrolled as undergraduate or graduate students in a French-speaking university in Montreal. All participants spoke at least some English, with English proficiency self-ratings ranging from beginner to near-native[10]. Some participants spoke additional non-native languages. Table 3.1 below provides a summary of the native French speakers' background information, including age, percent weekly usage of French, and percent weekly usage of English.

[10] English self-rating was coded numerically (beginner=1, intermediate=2, advanced=3, near-native=4), and was included in statistical models to check if it modulated any priming effects. There was no influence of English proficiency on priming in behavioral or EEG data for the native French speakers.

Table 3.1. Language Background, native French speakers

	Age	% French	% English
Mean	22.5	82.8	12.9
St. Dev.	4.9	20.1	14.9
Range	19- 41	30 - 100	0 – 60

In addition to the native French speakers, 26 native English speakers who learned French as a second language participated in the EEG study. All participants were paid for their participation. The non-native French speakers grew up in the United States (n=10) or English-speaking Canadian provinces (n=16) in households where English was the only spoken language. None of the French learners began learning French before age 10. Many of the participants were currently enrolled as undergraduate or graduate students at English-speaking universities in Montreal, and other participants were working professionals living in Montreal. The non-native French group filled out language background questionnaires where they provided information about their age of first exposure to French (AoE), years of French language instruction (Yrs Inst), their percent weekly usage of French (% French), and years living in Montreal[11] (Yrs Montreal) (see Appendix A). As a measure of proficiency, the French learners completed the LexTale-inspired lexical decision task (described above). A summary of the L2 French speakers is provided in Table 3.2 below. In Experiment 1, the French learners' cloze scores and LexTale scores were highly correlated (Pearson's correlation value = 0.68, p<.001), which would be predicted if both measures are attempting to capture French proficiency. In Experiment 2, the French learners only completed the LexTale proficiency measure as to avoid an excessively long visit to the lab.

[11] On the language background questionnaire, participants were asked about their time spent immersed in a French-speaking environment. None of the L2 learners had any significant time in a French-speaking environment that was not Montreal, so the data are presented as time in Montreal, rather than time of French immersion.

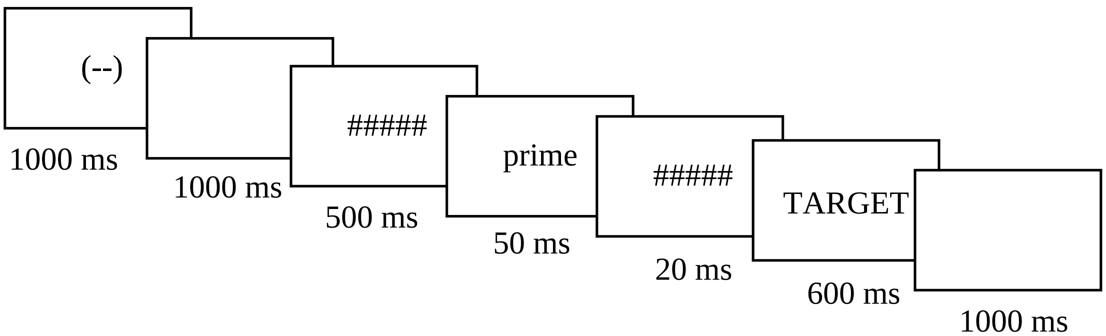
Table 3.2. Language background and proficiency for L2 French group

	Age	AoE	Yrs Inst	%French	Yrs Montreal	LexTale
Mean	22.8	13.6	5.4	12.6	3.1	0.62
St. Dev	5.6	3.7	3.2	10.1	2.6	0.9
Range	18 - 42	10 - 26	1 - 14	1 - 30	0.25 - 10	0.49 – 0.8

Procedure

This study used a masked-priming lexical decision task during EEG recording. Participants wore an electrode cap (WaveGuard EEG cap, eemagine Medical Imaging Solutions, Germany) while sitting in front of a computer screen in a quiet testing room. A schematic of the structure of a given trial is provided in Figure 3.1. Prior to the experiment, written instructions were provided on the screen in French for all participants. The instructions informed the participants that they would be seeing strings of letters and that their task was to decide if the string was a real French word or not. They were told that it was not a spelling test, so they should judge whether the exact letter string they saw on the screen was a real word or not. They were told to click the left mouse button with their right index finger if they believed the letter string was a real French word, and to click the right mouse button with their middle finger if they believed the letter string was not a real French word. The experimenter answered questions and confirmed that the participants understood the task in the participant's native language. Participants were instructed to blink when they saw the fixation point (i.e., **(--)**) at the beginning of a trial, and to try to avoid blinking when the pound signs and the letter string were on the screen. They were not given explicit instructions about responding to the target word as quickly as possible, and were told that it was acceptable for them to guess if they were unsure whether the target was a word or not. If participants asked about responding quickly they were instructed to try to keep up with the pace of the experiment. The experiment was divided into four blocks to allow for short breaks. The experiment took approximately 45 minutes to complete, not including the time spent preparing the electrode cap (which took approximately 30 minutes to prepare).

Figure 3.1. Experiment 2, Event Trial Structure[12]



Stimuli

The real-word stimuli in the EEG study were exactly the same as the stimuli in Experiment 1 except for the change of one unrelated prime for the orthographic condition (*bâtons* → *battons*). *Bâtons* is a conjugated form of the verb *bâter* (‘to saddle an animal’), whereas *battons* is a conjugated form of the verb *battre* (‘to beat/hit’). This substitution was suggested by a speaker of Quebec French who was unfamiliar with the existence of the verb *bâter*.

As in Experiment 1, all targets the stem form of regularly conjugated –*er* French verbs, and primes were inflected with the first-person plural –*ons* (except in the identity condition where the prime was also the stem form). The real-word target stimuli were in one of four conditions:

[12] The trial structure included both a forward mask (before the prime) as well as a backward mask (after the prime). This structure is used in many masked priming studies (e.g., Royle et al., 2012) as a means of further masking the prime from visual perception. Morphological priming is not influenced by the presence or absence of the second (backward) mask (e.g., Experiment 1; Royle et al., 2012).

identity (ID), morphological (Morph), orthographic (Orth), or semantic (Sem). There were 36 different target items for each of the four conditions, resulting in 144 different target words. Each target item in each of the four conditions was created with two prime words: a related prime and an unrelated prime. The four condition names describe the relationship between the prime and target words in the related version.

Target items were controlled across conditions for letter length ($F(3,140) <1$, $p>.62$) and frequency (in words per million, from the Lexique database, $F(3,140) <1$, $p>.69$). Prime words were controlled within and across conditions for length ($F(2,105) <1$, $p>.68$) and frequency ($F(2,105) <1$, $p=.8$). A summary of the mean length (standard deviation) and mean frequency (standard deviation) are provided in Table 3.3 below. A complete list of all items is provided in Appendix D.

Table 3.3. Stimuli Mean (SD) Length (top row) and Frequency (bottom row)

Condition	Target		Related Prime		Unrelated Prime	
Morph	PENSE ‘think’	5.25 (1.02); 22.48 (31.63)	pensons ‘think’	7.25 (1.02) 0.86 (1.66)	brûlons ‘burn’	7.25 (1.02) 0.28 (0.57)
Orth	BOUGE ‘move’	5.03 (0.75); 27.44 (51.26)	boudons ‘avoid’	7.11 (0.89) 0.59 (2.69)	tissons ‘weave’	7.14 (0.87) 0.36 (0.60)
Sem	HURLE ‘yell’	5.46 (0.89); 33.44 (44.52)	crions ‘scream’	7.31 (1.01) 0.91 (2.14)	bayons ‘gawk’	7.33 (0.96) 0.48 (1.57)
ID	DANSE ‘dance’	5.25 (1.11); 23.98 (37.37)	danse ‘dance’	5.25 (1.11) 23.98 (37.37)	prônons ‘advocate’	7.25 (1.11) 0.65 (0.97)

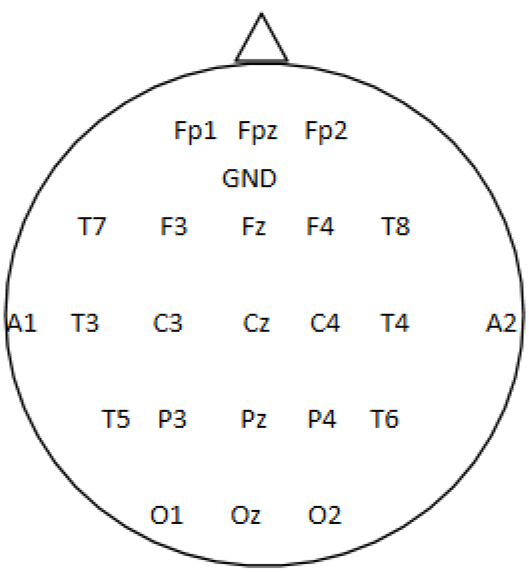
In addition to the 144 real-word targets, 144 nonce targets were created, each with 2 real-word primes. These targets were created to be orthographically and phonologically possible French words that resemble a $1^{st}/3^{rd}$-person singular *–er* verb (i.e., they all ended with *–e*). Designing the nonce target items in this way made it so the only way to distinguish real words from nonce words was lexical knowledge. Additionally, using real-word primes for the nonce targets made it so the lexical status of the prime did not predict the lexical status of the target. There were a number of changes of nonce targets between Experiment 1 and Experiment 2 to better control for nonce targets being too similar to real French words (e.g., differing only in 1 letter). The nonce targets for Experiment 2 are included in Appendix F.

All participants saw each target word twice throughout the experiment; once with a related prime, once with an unrelated prime. In one presentation of a given target word the prime was presented in lowercase and the target was presented in uppercase. In the other presentation of the same target word letter case was reversed to balance presentation manipulations across experiment lists (similar to Royle et al., 2012). The computer program Mix (van Casteren & Davis, 2006) was used to pseudorandomize the presentation of stimuli. The pseudorandomization ensured that the two presentations of a given target word were separated by at least 200 intervening trials. Additional pseudorandomization specifications included maximum of three target types (word/nonce) in a row, and a maximum of 2 items per condition in a row. The median target length (in letters) was calculated, and targets were coded as belonging to either the top or bottom median. The Mix pseudorandomization program then set a maximum of 4 sequential presentations of target items within a target median class. Experiment presentation lists were created to balance whether a target was first seen with a related or unrelated prime, as well as the letter case assignment for unrelated and related primes.

EEG Recording and analysis

The EEG signal was recorded continuously at 512 Hz with an online band-pass filter of 0.05 – 100 Hz. Participants wore a 64 channel WaveGuard EEG Cap (eemagine Medical Imaging Solutions, Germany) with embedded Ag/AgCl scalp and mastoid electrodes with noise-shielded cables. Twenty-three of the 64 electrodes embedded in the cap were used for recording: Fp1/2, Fpz, F7/8, F3/4, Fz, T3/4, C3/4, Cz, T5/6, P3/4, Pz, O1/2, Oz, A1/2 (mastoids). All other electrodes in the cap were deactivated during recording. Electrodes were arranged according to the montage shown in Figure 3.2. There were no eye-electrodes placed on the face. Impedance for all electrodes was kept below 5 KΩ. The EEG signal was amplified with an ANT amplifier (ANT-Neuro), referenced online to the left mastoid.

Figure 3.2. Electrode montage



All offline EEG signal processing was carried out using the EEProbe analysis software (ANT; Enschede, Netherlands). After recording, the EEG signal was re-referenced offline to the average of both mastoid electrodes (A1 and A2). The data were then filtered with a band-pass filter of 0.3 – 30 Hz. Eye-blinks and other artifacts were rejected using a 30 Hz standard deviation criterion with a 200 ms moving-window method. This resulted in removing 6.8% of the native French speaker data and 11.2% of the non-native French data. The recordings were epoched into time-windows beginning 570 ms before the target onset (i.e., -570 ms) until 1100 ms post target onset. The artifact rejection time-window was -470 ms to 700 ms. The artifact rejection time-window is smaller than the epoch time-window because many participants blinked after making their lexical decision, and extending the artifact rejection time-window the full length of the epoch would have resulted in an unacceptable amount of data loss for many participants. Though the epoch lasted until 1100ms after target presentation, the time-window analyses (below) do not exceed 500 ms post-target onset. The baseline correction applied to the EEG signal was -470 ms to -270 ms. This is a point in each trial where the initial mask is still on the screen. It is important for the baseline correction to be a point in the epoch where two conditions that will be compared (i.e., related vs unrelated primes) do not differ (for discussion, see Steinhauer & Drury, 2012).

Results: Accuracy and reaction times

Accuracy results are reported by condition for each group in Table 3.4 below. For the Nonce items, an accurate response is indicating “not word”, using the right mouse-button.

Table 3.4. Lexical decision accuracy by condition (percent)

Condition	L1 French	L2 French
Identity	94	84
Morphological	96	85
Orthographic	90	79
Semantic	96	83
Nonce	96	71

The trials with nonce targets were removed prior to analyses on accuracy data because of interest was checking if prime relatedness influenced accuracy in recognizing French words. Accuracy data were analyzed using a logistic regression model in R. Model selection was carried out by first maximally fitting a generalized linear model (*glm*) with Condition, Relatedness, and Group (called 'lang' in the model code), with all two-way and three-way interactions. Terms were removed one at a time and models were compared using log-likelihood ratio tests to determine if a given term significantly contributed to the fit of the model. The final model that best fits the model included Condition, Relatedness, and Group, as well as the interaction term of Condition x Group as fixed effects. The R code structure is provided below for reference. The colon between variables indicates an interaction term for those variables.

```
glm(accuracy ~ Condition + Related + lang + Condition:lang, data=data,
family="binomial")
```

Each categorical variable in the model has one level that is treated as the baseline to which other levels are compared. The baseline levels in the accuracy model were Identity for the Condition variable, Unrelated for the Relatedness variable, and L1 French for the Group variable. The results of the model reveal a significant effect of Group (z (10638) = -9.761, p<.001), indicating that the accuracy overall for the L2 French group was significantly lower than the L1 French group. There was an effect of Condition for the Morphological items (z (10638) = 2.248, p<.03), indicating that compared to the baseline Identity items for the L1 group, Morphological items had higher accuracy. There was a similar effect of Condition for the Semantic items (z (10638) = 2.173, p<.03), indicating higher accuracy in Semantic items than Identity items for the L1 group. There was also a significant effect of Condition for the Orthographic items, but in the opposite direction (z (10638) = -4.332, p<.001), indicating that compared to the Identity baseline, Orthographic items had overall lower accuracy for the L1 group. Finally, there was a significant interaction of Condition x Group for the Semantic items (z (10638) = -2.258, p<.03), indicating that whereas the L1 French group had higher accuracy in the Semantic items compared to the Identity items, this was not the case for the L2 French group.

Overall, the analyses on lexical decision accuracy do not reveal any priming effects. That is, the prime being related or not to the target did not modulate how accurately participants made their lexical decision.

To analyze the reaction time data, items with incorrect responses were removed from the dataset. This resulted in a loss of 6.1% of the native French speaker data and 18.5% of the non-native French data. The reaction time data were further cleaned by removing any reaction times shorter than 300 ms or longer than 3000 ms. Reaction times were then converted to z-scores for each participant, and reaction times 2.5 standard deviations beyond a participant's mean were removed from the dataset. This additional cleaning resulted in a loss of 3% of the L1 French speakers' data, and 3.6 % of the L2 French speakers' data. Table 3.5 below shows the mean reaction times (in ms) for the Related and Unrelated items in each condition, after the dataset was cleaned. The priming effect (Related minus Unrelated) is also given for each condition. Negative priming values indicate facilitation of target recognition for the related primes relative to the unrelated primes.

Table 3.5. Mean reaction times (ms) and priming effects

Condition	**Relatedness**	**L1 French**	**Priming (L1)**	**L2 French**	**Priming (L2)**
Identity	Related	653	-20	631	-43
	Unrelated	673		674	
Morphology	Related	655	-25	638	-33
	Unrelated	680		671	
Orthographic	Related	673	-6	657	-9
	Unrelated	779		666	
Semantic	Related	669	-7	667	+11
	Unrelated	676		656	

To visualize the reaction time data, bar plots are provided in Figure 3.3 (L1 French) and Figure 3.4 (L2 French) below.

Figure 3.3. Reaction times, L1 French

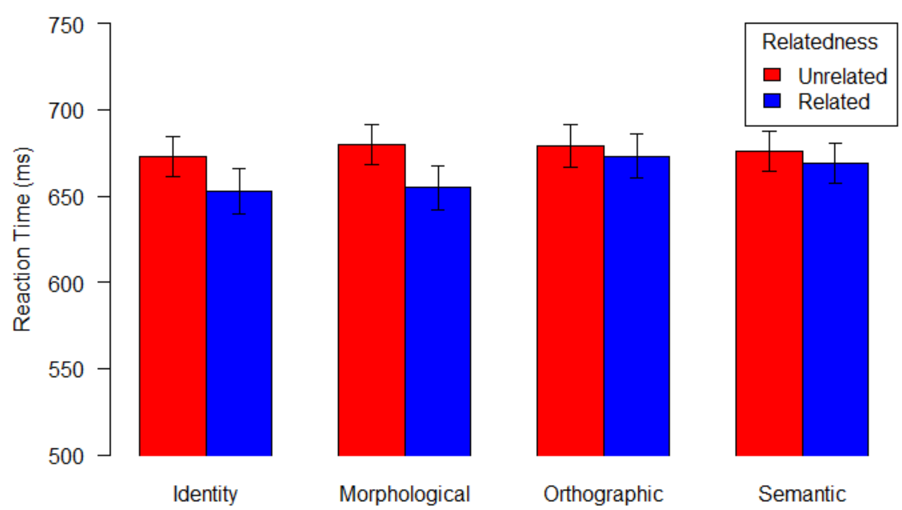
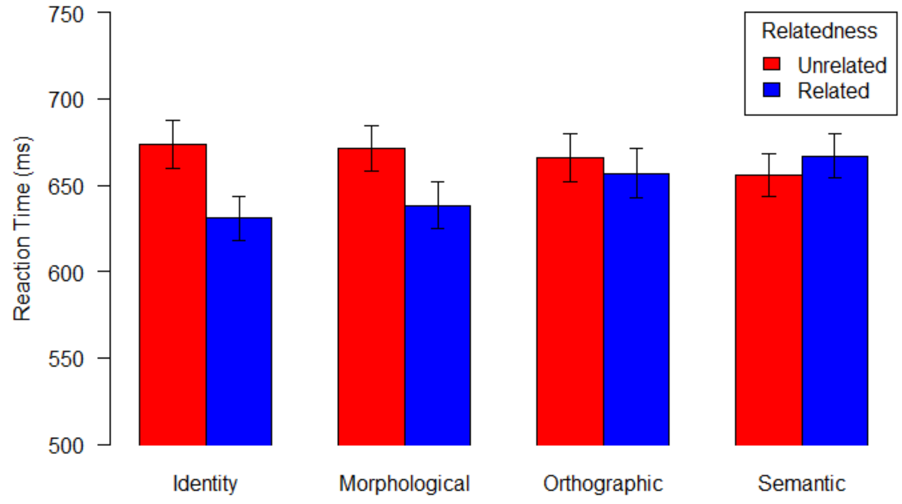


Figure 3.4. Reaction times, L2 French



The reaction times were analyzed using linear mixed-effects models, using the *lmer* function in the *lme4* R package. The R package *lmerTest* was used to obtain *p*-values for the models, and the R package *LMERConvenienceFunctions* was used for backwards stepwise model selection, similar to model selection in Experiment 1 (above). The dependent variable in the models was the log-transformed reaction times. Model fitting began with a maximally fit model with Condition, Relatedness, and Group, as well as all two-way and three-way interaction terms as fixed effects. Subject was included as a random intercept, and Relatedness was included as a random slope on the Subject random intercept. The *bfFixefLMER_F* function was used to remove terms one at a time and compare simpler models to more complex models using log-likelihood ratio tests.[13] This allowed for the simplest model that best fit the data to be selected. The final model included Condition and Relatedness, as well as the interaction of Condition x

[13] The function used for model selection in the reaction time models was the same method as what was manually done in the accuracy models. The automatic function is only available in R for linear models (like *lmer*), not logistic models (like *glm*).

Relatedness, as the fixed effects. Subject was included as a random intercept with Relatedness as a random slope. Group was not included in the model because it did not improve the model's fit of the data. The R code structure is provided below for reference. The colon between variables indicates an interaction term for those variables.

```
lmer(log_rt ~ Condition + Related + (1+Related| Subject) +
Condition:Related, data)
```

As was the case in previous analyses, the baseline levels for the model were Identity for the Condition variable, and Unrelated for the Relatedness variable. The results of the model reveal a significant effect of Relatedness (t (12659) = -7.131, p<.001), indicating that, in the Identity condition, related primes elicited significantly faster reaction times compared to unrelated primes. There was a significant interaction of Condition x Relatedness for the Orthographic condition (t (12659) = 3.979, p<.001), as well as a significant interaction of Condition x Relatedness for the Semantic condition (t (12659) = 5.787, p<.001). These two interactions indicated that the effect of Relatedness in the Identity condition was different in the Orthographic and Semantic conditions.

The interactions of Condition x Relatedness were further investigated by running separate models on Orthographic items and Semantic items. The model investigating the effect of Relatedness in the Orthographic items only included Relatedness as a fixed effect, and Subject as a random intercept with Relatedness as a random slope. The dependent variable was log-transformed reaction times. The model revealed no significant effect of Relatedness, even without a Bonferroni correction for multiple comparisons (t (2981) = -1.784, p>.08; with

Bonferroni correction *p*>.16). The results of the follow-up model for the Orthographic items indicated that orthographically related primes do not offer significant facilitation in target recognition compared to unrelated primes. The follow-up model for the Semantic items had the same structure as the model for the Orthographic items. The results of the Semantic model revealed no effect of Relatedness (t (3215) = 0.337, p>.7). This indicates that semantically related primes offer no facilitation in target recognition compared to unrelated primes.

The results of the reaction times analyses are similar to the reaction times analysis in Experiment 1 where participants were put under time pressure to make lexical decisions in a masked priming task. Similar to Experiment 1, both native and non-native French speakers show facilitation in target recognition when primes are either identical or morphologically related to the target, relative to unrelated primes. Additionally, like in Experiment 1, this facilitation cannot be attributed to shared orthography or semantic overlap between primes and targets because neither orthographically related primes nor semantically related primes offered significant priming relative to unrelated primes.

The analyses of reaction times with native and non-native French speakers revealed no difference between the native French group and the non-native French group in terms of priming effects. However, of interest to this study is whether all non-native French speakers show this effect of morphological processing, or if morphological processing is only found in more advanced learners. To test if proficiency modulates morphological processing, the reaction times for the L2 French group were tested separately so that proficiency could be considered a factor.

To investigate the potential effect of proficiency on morphological processing in the L2 French group, proficiency scores (as measured by the LexTale task) were first log-transformed to allow for a normal distribution. A linear mixed-effects model was initially fit using the *lmer* function in the *lme4* R package. The model included log-transformed reaction times as the dependent variable, and Condition, Relatedness, and log-transformed proficiency (called 'log_lextale' in the model code), as well as all two-way and three-way interactions, as fixed effects. Subject was included as a random intercept with Relatedness included as a random slope. As was done in previous analyses, final model selection was carried out using the *bfFixefLMER_F* function in the *LMERConvenienceFunctions* R package by way of log-likelihood ratio tests. The final model included Condition, Relatedness, and the interaction of Condition x Relatedness as fixed effects, and Subject as a random intercept with Relatedness as a random slope. The R code structure is provided below for reference. The colon between variables indicates an interaction term for those variables.

```
lmer(log_rt ~ Condition + Related +(1+Related|Subject) +
Condition:Related, data.L2)
```

As in previous analyses, the baseline levels were Identity for Condition, and Unrelated for Relatedness. Proficiency was not included because it did not improve model fit. The model revealed a significant effect of Condition for Semantic items (t (5832) = -2.138, p<.05), indicating that the unrelated Semantic items had faster reaction times than the unrelated Identity items. There was also a significant effect of Relatedness (t (5832) = -6.215, p<.001), indicating that in the Identity condition, the related primes elicited faster lexical decisions than unrelated primes. There was an interaction of Condition x Relatedness for the Orthographic items (t (5832) = 3.513, p<.001), as well as an interaction of Condition x Relatedness for the Semantic items (t (5832) = 5.801, p<.001). These interactions indicate that the effect of Relatedness found in the baseline Identity condition is different in the Orthographic and Semantic conditions.

To further investigate the interactions, follow-up models were conducted on Orthographic and Semantic items separately. Both models shared the structure of using log-transformed reaction times as the dependent variable, Relatedness as a fixed effect, and Subject as a random intercept with Relatedness as a random slope. The model for Orthographic items revealed no effect of Relatedness (p>.3). The model for Semantic items also revealed no effect of relatedness (p>.1). The analyses on the L2 French group reveal the same pattern of identity and morphological priming that was found in the model with L1 and L2 French groups together. Importantly, the analyses on the L2 French group alone revealed that proficiency does not modulate the priming effects. These findings are similar to the findings in Experiment 1, which indicate that morphological priming can be found across the wide range of L2 proficiency levels.

EEG Results

EEG amplitude data were analyzed in two time-windows, 100 – 300 ms post target onset, and 300 – 500 ms post target onset. These time-windows are characteristic time-windows for, respectively, the N250 and N400 EEG components of interest in this study. Recall that the N400 component is where effects of morphology are predicted to appear, whereas the N250 is predicted to find effects of orthographic overlap between prime and target, independent of morphological overlap (e.g., Royle et al., 2012). For each time-window, the mean amplitude of each participant was calculated for each electrode for each condition. Electrodes were coded for hemisphere (left, midline, right) and for anteriority (anterior, central, posterior). Linear mixed-effects models (*lmer* function of the *lme4* R package) were used to analyze the amplitude data for each time window. Model *p*-values were calculated with the *lmerTest* R package. Models were initially fit with Condition (ID, Morph, Orth, Sem), Relatedness (Unrelated, Related), Group (L1, L2), Hemisphere (left, mid, right), and Anteriority (anterior, central, posterior) as fixed effects, along with all interaction terms for the five variables. Subject was included as a random intercept, along with Relatedness as a random slope. The maximally fit model was then progressively minimized using the *LMERConvenienceFunctions* R package, using log-likelihood ratio tests to compare more complex models to simpler models. The final models that best fit the data for each time-window are described in the sections below for each time-window.

The waveform plots for the midline electrodes (Fz, Cz, Pz) are provided in Figures 3.5 and 3.6 below for native and non-native French speakers (respectively). Note that in these waveform plots negative voltage is plotted upwards. For each condition (Identity, Morphology, Orthographic, Semantic), each plot shows two voltage lines: the related prime items (in blue) and the unrelated prime items (in red). These plots reflect the group mean voltage for the group, and do not reflect individual variability (which is accounted for in the statistical models presented below). These plots were created using the *erpR* package in R (Arcara & Petrova, 2015).

Figure 3.5. Native French, Midline electrodes

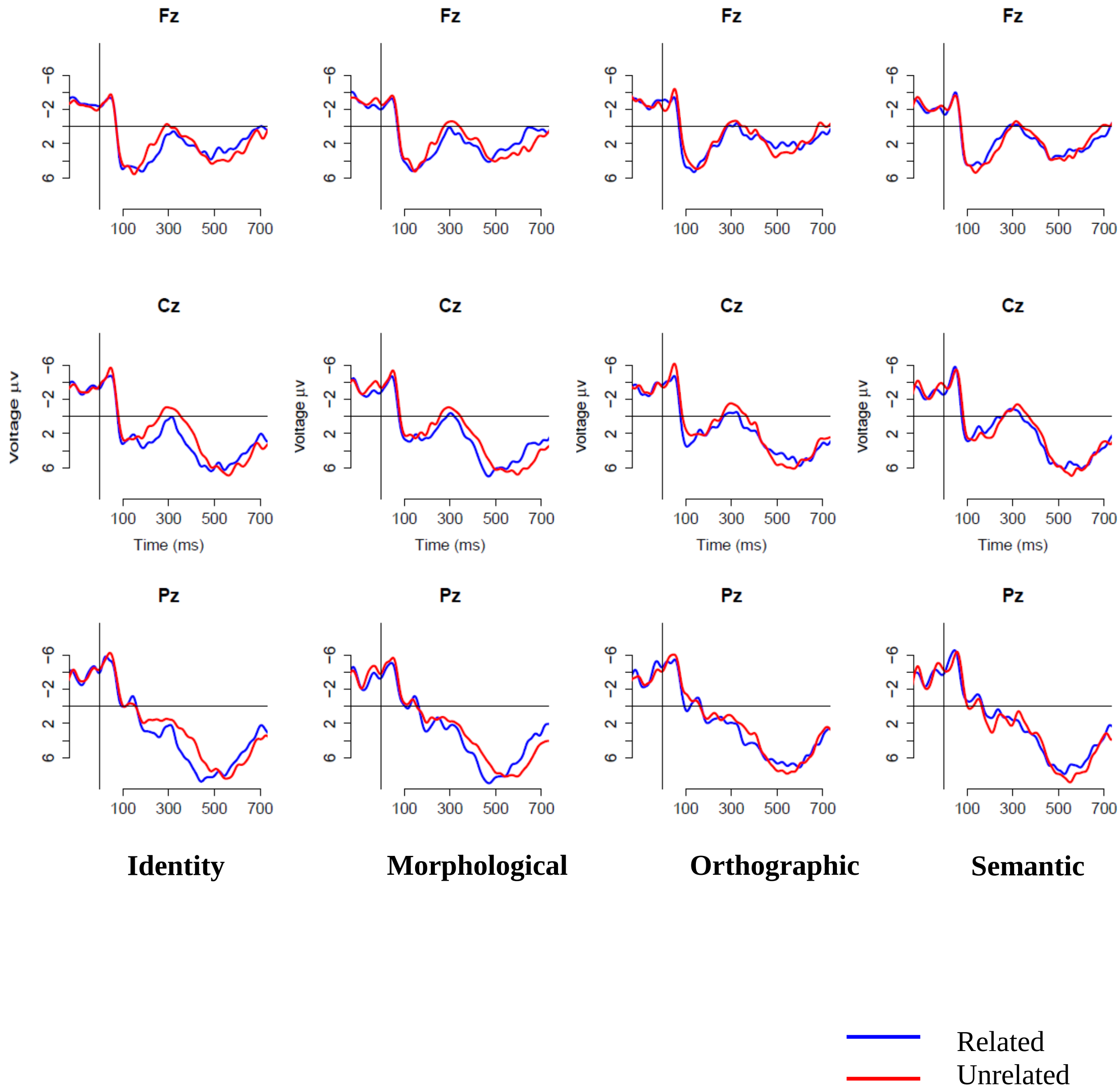
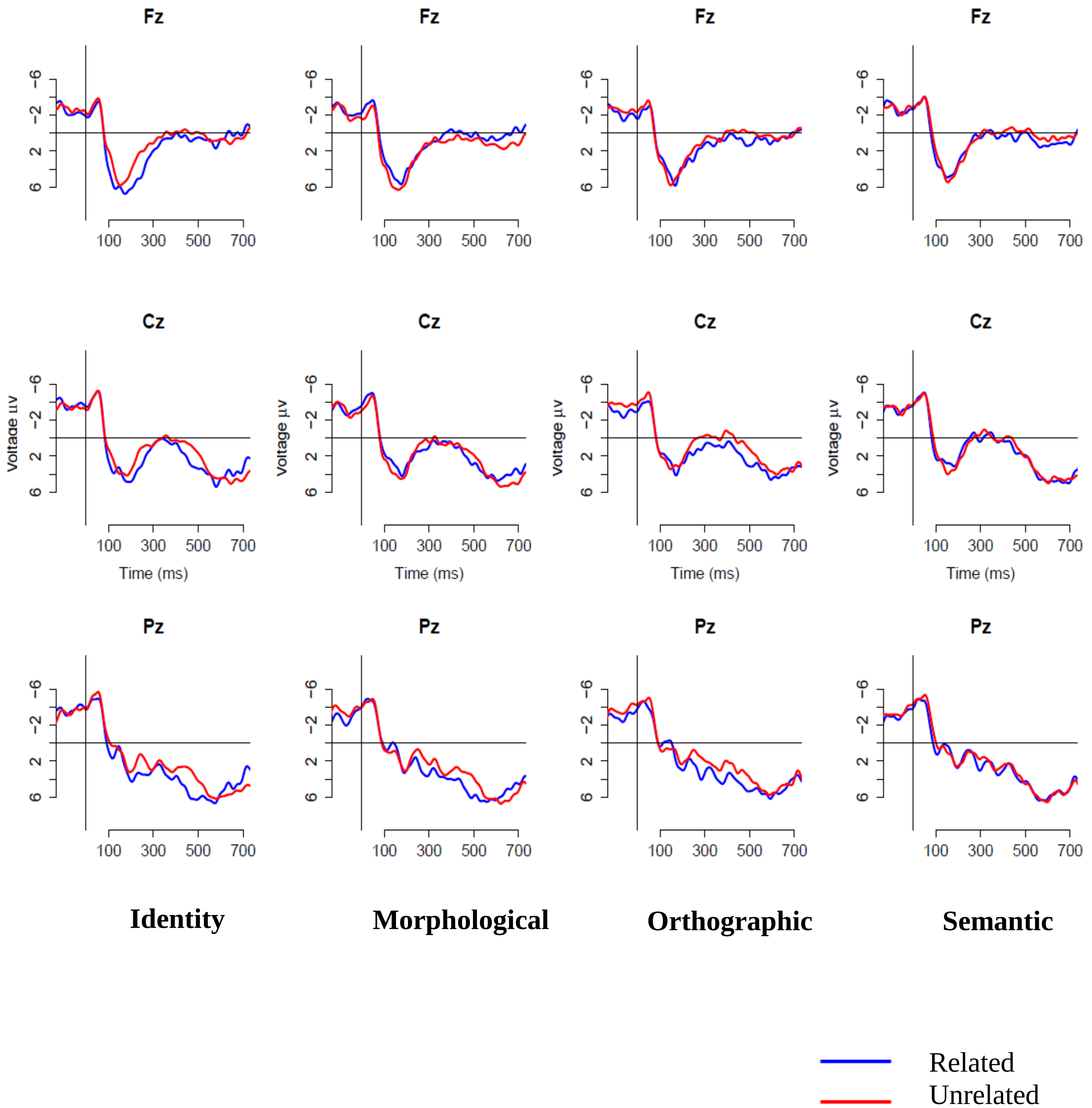


Figure 3.6. Non-native French, Midline electrodes



300 – 500 ms time-window analysis, L1 and L2 French

The aim of Experiment 2 is to investigate morphological processing at the brain level. Effects of morphological priming are predicted to appear in the N400 time-window, so the analyses pertaining to this EEG component are presented first. It is predicted that when a prime and target share morphology, the negativity in the 300 – 500 ms time-window is expected to be attenuated (i.e., more positive) compared to when the prime and target do not share morphology. Shared orthography or shared semantics between prime and target words are predicted not to attenuate the negativity in this time-window.

The analysis of the 300 – 500 ms time-window began by including both L1 and L2 French speakers together in the same model. The model was first maximally fit and then simplified through a backwards stepwise function to select the simplest model that best fits the data. The final model included Condition, Relatedness, Group (called 'lang' in the model code), Hemisphere, and Anteriority (called 'antpos' in the model code), as well as interactions of Condition x Relatedness, Condition x Group, Related x Group, Group x Hemisphere, Condition x Anteriority, Relatedness x Anteriority, Group x Anteriority, Hemisphere x Anteriority, Condition x Relatedness x Group, and Condition x Relatedness x Anteriority as fixed effects. Subject was included as a random intercept with Relatedness as a random slope. The R code structure is provided below for reference. The colons between multiple variables indicates an interaction term for those variables.

```
lmer(mean ~ Condition + Related + lang + hemisphere + antpos + (1 |
subj) + Condition:Related + Condition:lang + Related:lang +
lang:hemisphere + Related:antpos + lang:antpos + hemisphere:antpos +
Condition:Related:lang, data = time300)
```

The final model summary is very complex due to so many interaction terms, so only the relevant results will be discussed here. The complete *lmer* summary can be found in Appendix I. The model reveals a number of interactions with Group, including a three-way interaction of Condition x Relatedness x Group (t (8439) = -2.461, p<.02), and interactions of Group and topographical factors. Follow-up models are used to investigate the effect of priming for each group separately.

300 – 500 ms time-window analysis, L1 French

The model selected to analyze the L1 French EEG data in the 300 – 500 ms time-window included Condition, Relatedness, Hemisphere, and Anteriority, as well as interactions of Condition x Relatedness, Relatedness x Anteriority, and Hemisphere x Anteriority as fixed effects. Subject was included as a random intercept, with Relatedness as a random slope. The baseline levels are the same as described above in previous models. The results of the *lmer* model are shown in Table 3.6 below.

Table 3.6. L1 French, 300 – 500 ms results

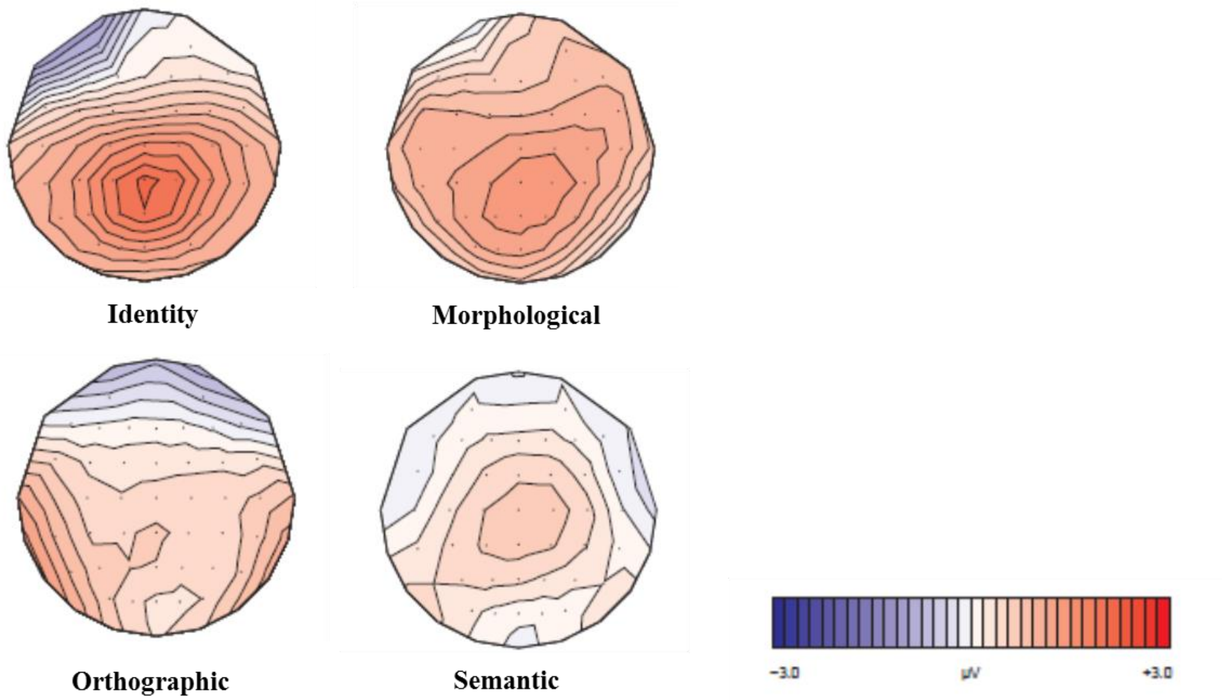
Number of obs: 4320, groups: subj, 27

Fixed effects:

	Estimate	Std. Error	df	t value	Pr(>|t|)	
(Intercept)	2.28403	0.51053	42.00000	4.474	5.86e-05	***
Conditionmorph	-0.22424	0.17644	4250.00000	-1.271	0.203825	
Conditionorth	-0.41552	0.17644	4250.00000	-2.355	0.018566	*
Conditionsem	-0.31532	0.17644	4250.00000	-1.787	0.073992	.
Relatedrel	0.87871	0.29688	117.00000	2.960	0.003729	**
hemisphereleft	-0.10785	0.24160	4250.00000	-0.446	0.655329	
hemisphereright	0.46757	0.24160	4250.00000	1.935	0.053017	.
antposant	-0.37605	0.30194	4250.00000	-1.245	0.213044	
antpospost	0.59281	0.26649	4250.00000	2.225	0.026166	*
Conditionmorph:Relatedrel	0.16309	0.24952	4250.00000	0.654	0.513389	
Conditionorth:Relatedrel	-0.44865	0.24952	4250.00000	-1.798	0.072246	.
Conditionsem:Relatedrel	-0.50207	0.24952	4250.00000	-2.012	0.044271	*
Relatedrel:antposant	-0.68292	0.23101	4250.00000	-2.956	0.003132	**
Relatedrel:antpospost	0.03697	0.22492	4250.00000	0.164	0.869439	
hemisphereleft:antposant	-0.73283	0.33205	4250.00000	-2.207	0.027367	*
hemisphereright:antposant	0.08890	0.33205	4250.00000	0.268	0.788910	
hemisphereleft:antpospost	-1.04531	0.30133	4250.00000	-3.469	0.000528	***
hemisphereright:antpospost	-1.72405	0.30133	4250.00000	-5.721	1.13e-08	***

The results of the analysis reveal a significant effect of Relatedness, indicating that the negativity found in the 300 – 500 ms time-window is attenuated at the center of the scalp for Identity primes. There is a significant interaction of Condition x Relatedness for Semantic items, indicating that the priming effect in the Identity condition differs in the Semantic condition. There is also a marginally significant interaction of Condition x Relatedness for the Orthographic condition. Importantly, there is an interaction of Relatedness x Anteriority for anterior electrode sties. This interaction can be understood by looking at the topoplots in Figure 3.7 below where the attenuation of the negativity is strongest over central and posterior sites. To fully understand the interaction of Relatedness x Anteriority, follow-up models were run for each level of Anteriority (anterior, central, posterior). When analyzing the priming effects at different scalp locations, it is important to keep in mind that the N400 component is typically maximal at centro-posterior sites on the scalp (e.g., Morris, Grainger, & Holcomb, 2013). Morphological priming is thus expected to be found at centro-posterior sites, and is less likely to appear at anterior sites.

Figure 3.7. Topoplots (Related – Unrelated) 300 – 500 ms time-window, L1 French only



The first follow-up model is just for anterior electrodes in the 300 – 500 ms time-window for the L1 French speakers. The model that best fit the data included only Condition and Hemisphere as fixed effects, with no interaction terms. The results reveal an effect of Condition for Orthographic items (*t* (1507) = -2.980, *p*<.01), indicating that overall Orthographic items have a more negative amplitude than the baseline Identity items. There was also an effect of Hemisphere for both the left hemisphere (*t* (1507) = -4.282, *p*<.001) and right hemisphere (*t*

(1507) = 2.835, $p<.01$), which indicate that the left hemisphere is more negative than the midline, and the right hemisphere is more positive than the midline. This follow-up model shows that there is no effect of Relatedness for any condition at the anterior electrode sites.

The best model investigating the central electrodes sites included Condition, Relatedness, and Hemisphere, as well as the interaction of Condition x Relatedness. The results showed an effect of Relatedness (t (1071) = 3.465, $p<.001$), indicating that in the Identity condition, the mean amplitude is more positive for related primes compared to unrelated primes. There is also an effect of Condition for Orthographic items (t (1071) = -2.228, $p<.03$), indicating that mean amplitude is overall more negative for Orthographic items compared to Identity items. There is also an interaction of Condition x Relatedness for the Semantic condition (t (1071) = -2.282, $p<.03$), indicating that the priming effect found in the baseline Identity condition is different in the Semantic condition. The lack of interaction for Condition x Relatedness for the Morphological and Orthographic conditions indicate that at the central electrodes, the priming effect is equal for Identity, Morphological, and Orthographic conditions.

The best model investigating the posterior electrode sites included Condition, Relatedness, and Hemisphere, as well as the interaction of Condition x Relatedness as fixed effects. The results show a significant effect of Relatedness (t (1719) = 3.617, $p<.001$), indicating that in the Identity condition, the related primes elicit a more positive amplitude than the unrelated primes. There is also an interaction of Condition x Relatedness for the Orthographic condition (t (1719) = -1.969, $p<.05$) and the Semantic condition (t (1719) = -2.703, $p<.01$). These interactions indicate that the priming effect found in the Identity condition is different in the Orthographic and Semantic conditions, whereas the lack of interaction of Condition x Relatedness for the Morphological condition indicates that the priming effect in the Identity condition is not different in the Morphological condition.

Overall, the analyses of the L1 French group in the 300 – 500 ms time-window show evidence of morphological priming. Only the Identity and Morphological primes significantly attenuate the negativity in the time-window compared to unrelated primes. Additionally, the topographic interactions in the models indicate that the priming effects are found at central and posterior sites, with morphological priming being distinct from orthographic priming at posterior sites. At the central sites the priming effect is equal for Identity, Morphological, and Orthographic primes. At the posterior sites the priming effect is equal for Identity and Morphological primes, but orthographically related primes do not elicit significantly more positive amplitudes compared to unrelated primes. These results are in line with the predictions regarding how morphological overlap between prime and target words will modulate the N400 component. When the prime word is morphologically related to the target word (either in the identity or morphological condition), the N400 time-locked to the presentation of the target word is significantly attenuated (i.e., more positive) compared to when the prime is unrelated to the target. Additionally, when the prime word is related semantically or orthographically to the target, the negativity is not significantly attenuated compared to when the prime is unrelated to that target. The EEG results in the native French speakers are thus consistent with the prediction that a morphological level of representation was accessed in the lexicon.

300 – 500 ms time-window analysis, L2 French

The best model to fit the L2 French data in the 300 -500 ms time-window included Condition, Relatedness, log-transformed LexTale (called ‘log_lextale’ in the model code), Hemisphere, and Anteriority (called ‘antpos’ in the model code), as well as interactions of Condition x Relatedness, Condition x log-transformed LexTale, log-transformed LexTale x Hemisphere, Condition x Anteriority, Relatedness x Anteriority, log-transformed LexTale x Anteriority, and Hemisphere x Anteriority. The R code structure is provided below for reference. The colon between multiple variables indicates an interaction term for those variables.

```
lmer(mean ~ Condition + Related + log_lextale + hemisphere + antpos +
(1 + Related | Subject) + Condition:Related + Condition:log_lextale +
log_lextale:hemisphere + Condition:antpos + Related:antpos +
    log_lextale:antpos + hemisphere:antpos ,time300)
```

Due to the complex structure of the model, only the relevant results will be discussed here. The full *lmer* summary is provided in Appendix J. The model reveals an effect of Relatedness (t (4129) = 2.946, $p< .01$), but also a number of interactions, including marginal interactions of Relatedness x Anteriority for both the anterior (t (4129) = -1.741, p=.082) and posterior (t (4129) = 1.749, p=.08) sites. There were also significant interactions of Condition x Relatedness for the morphological (t (4129) = -2.802, p<.01) and semantic (t (4129) = -2.537, p<.02) conditions. Follow-up interactions were carried out by splitting the data by anteriority. It would also be possible to carry out follow-up models by splitting the data by Condition, but of interest to the study is to compare how priming effects in different conditions compare to each other, so it is desirable to maintain the possibility of comparing conditions in follow-up models by resolving the topographic interactions first.

The best model for the anterior sites included Condition, Relatedness, log-transformed LexTale, and Hemisphere, as well as interactions of Condition x Relatedness, Condition x log-transformed LexTale, Relatedness x log-transformed LexTale, and Condition x Relatedness x log-transformed LexTale as fixed effects. The baseline levels were the same as used in previous models. The results of the model show no effect of Relatedness ($p>.3$). There was, however an interaction of Condition x Relatedness for the Semantic condition (t (1439) = -2.786, $p<.01$), as well as an interaction of Condition x log-transformed LexTale for the Semantic condition (t (1439) = 2.282, $p<.05$), and an interaction Condition x Relatedness x log-transformed LexTale (t (1439) = -2.901, $p<.01$). A follow-up model on Semantic items only revealed no significant effects of Relatedness, log-transformed LexTale, or an interaction of the two (all ps >.35). Overall, the results of the analyses for the anterior sites suggest that for the L2 group, there is no priming effect for any condition at anterior sites in the 300 – 500 ms time-window.

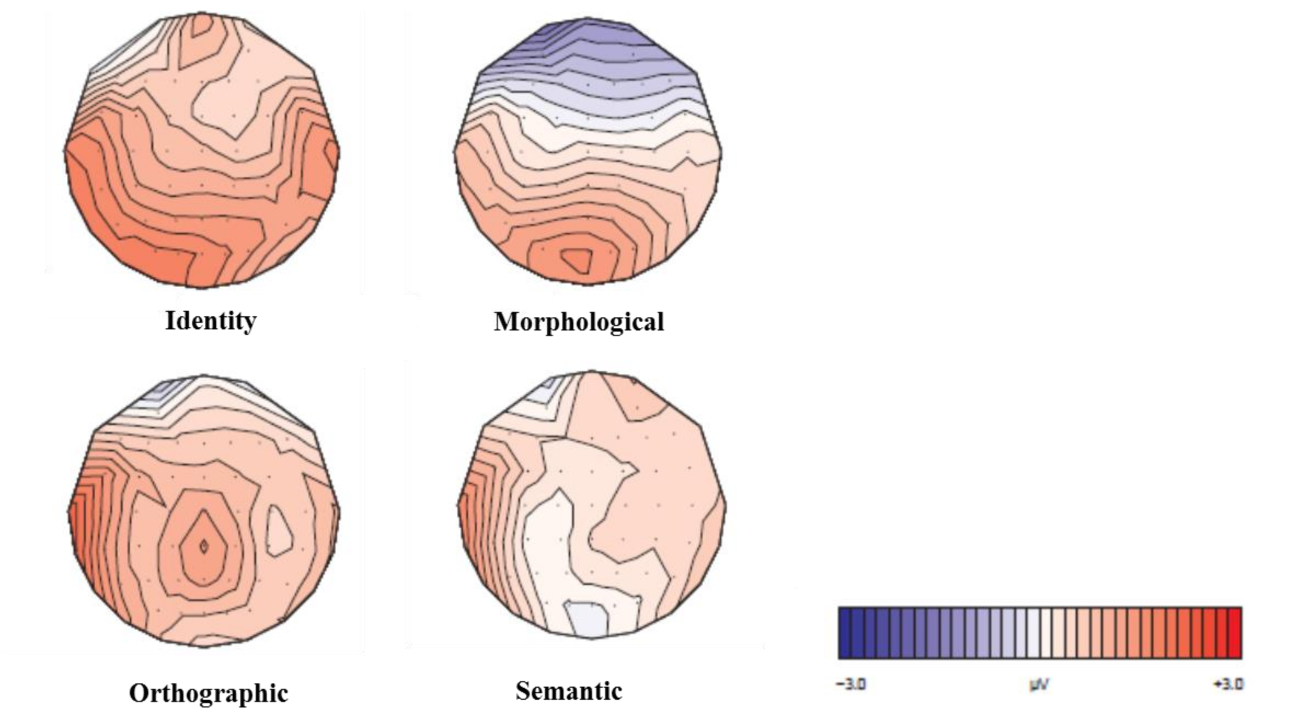
The best model for the central electrode sites included Condition, Relatedness, log-transformed LexTale, and Hemisphere, as well as interactions of Condition x Relatedness, and log-transformed LexTale x Hemisphere. The results show a significant effect of Relatedness (t (1028) = 2.493, $p<.02$) and an interaction of Condition x Relatedness for the Morphological condition (t (1028) = -2.121, $p<.05$). A follow-up model on Morphological items only revealed no effect of Relatedness ($p>.8$). Overall the analyses at the central electrode sites for the L2 French group in the 300 -500 ms time-window reveal similar priming effects for Identity, Orthography, and Semantic conditions, but no priming effect for the Morphological condition.

The best model for the posterior electrode sites included Condition, Relatedness, log-transformed LexTale, and Hemisphere, as well as interactions of Condition x Relatedness, Condition x log-transformed LexTale, and log-transformed LexTale x Hemisphere. The results reveal a significant effect of Relatedness (t (1649) = 5.063, p<.001), indicating that in the Identity (baseline) condition, related primes elicit significantly more positive amplitudes compared to unrelated primes (i.e., the negativity is attenuated). There is also a significant interaction of Condition x Relatedness for the Orthographic condition (t (1649) = -2.223, p<.03) and for the Semantic condition (t (1649) = -4.251, p<.001). These interactions indicate that the priming effect in the Identity condition is different in the Orthographic and Semantic conditions. The lack of interaction of Condition x Relatedness for the Morphological condition indicates that the priming effect in the Identity condition has the same pattern in the Morphological condition.

The priming differences for each condition can be visualized in the topoplots shown in Figure 3.8 (below). In these plots, the mean voltage (for all participants) for the unrelated prime was subtracted from the mean voltage for the related prime. Red colors indicate that this difference is positive (i.e., the N400 was attenuated). Overall, the analyses for the L2 group in the 300 – 500 ms time-window reveal that in the anterior region, no condition offers any priming effect for related primes. At central electrode sits, the L2 group shows a priming effect for the Identity, Orthographic, and Semantic conditions. This differs from the pattern at central sites for the L1 French group, who showed priming effects for Identity, Morphological, and Orthographic conditions. At the posterior electrode sites, the L2 French group showed priming effects for the Identity and Morphological conditions, which is the same pattern that was found in the L1

French group. Interestingly, despite the wide-range of the L2 group's proficiency levels, no interaction of Relatedness x log-transformed LexTale was found in any model. This indicates that proficiency (as measured in the study) does not modulate the priming effects.

Figure 3.8. Topoplots (Related – Unrelated) 300 – 500 ms time-window, L2 French only



Overall, the analyses of the 300 – 500 ms time-window for the non-native French speakers show evidence of morphological processing, similar to the findings in the native French speakers. The negativity in this time-window (the N400) was significantly attenuated by primes that share morphology with the target (i.e., the Identity and Morphological conditions). Like the native French speakers, the priming effect was found at posterior electrode sites. Importantly, the morphological priming cannot be explained by the fact that morphologically related words share orthography and semantics meaning; the Orthographic and Semantic primes did not offer significant priming compared to unrelated primes.

100 – 300 ms time-window analysis, L1 and L2 French

The second EEG component of interest to the present study is the N250. The 100 – 300 ms time-window was analyzed for primes modulating this component. Recall that this component is associated with early stages of lexical access, and is typically attenuated when the prime and target overlap in orthography (e.g., Royle et al., 2012). This component is not associated with morphological processing. As was done for the N400 analyses, the analyses for the N250 component involved first calculating the mean amplitude for each participant, at each electrode, for each condition.

The first model investigating the N250 component included both native and non-native French speakers together, and was initially maximally fit with the fixed effects of Condition, Relatedness, Group (called 'lang' in the model code), Hemisphere, Anteriority (called 'antpos' in the model code), as well as all interaction terms. Subject was included as a random intercept, with Related as a random slop. A backwards stepwise function was used to select the simplest model that best fits the data (according to log-likelihood ratio tests). The best model for the data in the first time-window included Condition, Relatedness, Group, Hemisphere, and Anteriority as fixed effects, along with the following interaction terms: Condition x Relatedness, Condition x Group, Relatedness x Group, Relatedness x Hemisphere, Group x Hemisphere, Group x

Anteriority, Hemisphere x Anteriority, and Condition x Relatedness x Group. Subject was included as a random intercept, with Relatedness included as a random slope. The R code structure is provided here for reference. The colon between multiple variables indicates an interaction term of those variables.

```
lmer(formula = mean ~ Condition + Related + lang + hemisphere +
antpos + (1 | subj) + Condition:Related + Condition:lang +
Related:lang + Related:hemisphere + lang:hemisphere + lang:antpos +
hemisphere:antpos + Condition:Related:lang, data = time100)
```

The baseline levels for each categorical variable were as follows: Condition = Identity, Relatedness = Unrelated, Group = L1 French, Hemisphere = midline, Anteriority = central. The summary of the *lmer* model of the time-window reports simple effects (as compared to main effects), which means that each level of each variable for all fixed effects is returned. The complete *lmer* summary of the model can be found in Appendix G. The results of the model show a number of interactions with Group (including a marginal interaction of Relatedness x Group, t (8451) = 1.797, p=.076, and significant interaction of Condition x Relatedness x Group, t (8451) = -4.365, p<.001). In order to better understand the priming effects in the early time-window, follow-up models were run for each language group separately.

100 – 300 ms time-window analysis, L1 French

The model selected for the native French speakers in the 100 – 300 ms time-window included Condition, Relatedness, Hemisphere, and Anteriority, as well as interaction terms for Condition x Relatedness, and Hemisphere x Anteriority. Subject was included as random intercept with

Relatedness as a random slope. The baseline levels were again Identity for Condition, Unrelated for Relatedness, midline for Hemisphere, and central for Anteriority. The results of the *lmer* model are shown in Table 3.7 below.

Table 3.7. L1 French, 100 – 300 ms results

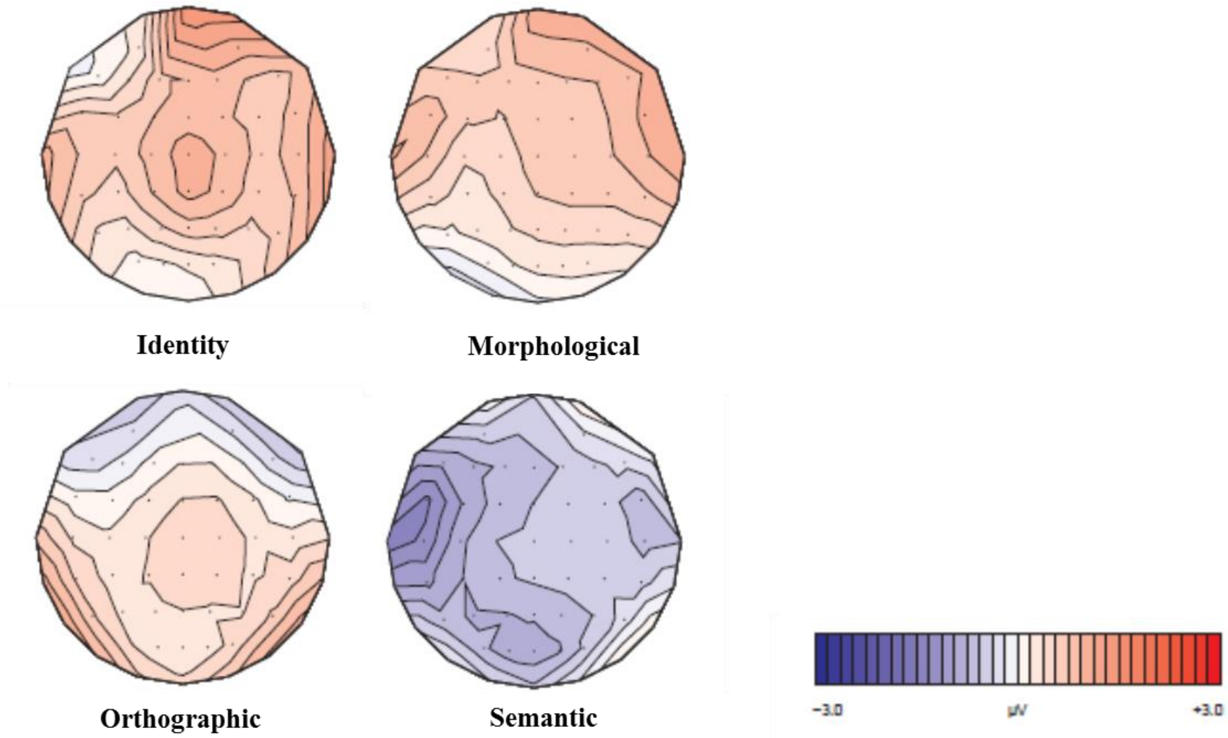
Number of obs: 4320, groups: subj, 27

Fixed effects:

	Estimate	Std. Error	df	t value	Pr(>|t|)	
(Intercept)	1.49625	0.40731	42.00000	3.674	0.000676	***
Conditionmorph	-0.24833	0.14949	4252.00000	-1.661	0.096752	.
Conditionorth	-0.22576	0.14949	4252.00000	-1.510	0.131066	
Conditionsem	0.11091	0.14949	4252.00000	0.742	0.458184	
Relatedrel	0.49364	0.26471	45.00000	1.865	0.068751	.
hemisphereleft	0.12309	0.20470	4252.00000	0.601	0.547653	
hemisphereright	-0.15201	0.20470	4252.00000	-0.743	0.457745	
antposant	1.58654	0.23636	4252.00000	6.712	2.17e-11	***
antpospost	-2.29441	0.20470	4252.00000	-11.209	< 2e-16	***
Conditionmorph:Relatedrel	-0.03028	0.21141	4252.00000	-0.143	0.886121	
Conditionorth:Relatedrel	-0.33615	0.21141	4252.00000	-1.590	0.111904	
Conditionsem:Relatedrel	-0.98495	0.21141	4252.00000	-4.659	3.28e-06	***
hemisphereleft:antposant	0.29381	0.28133	4252.00000	1.044	0.296375	
hemisphereright:antposant	0.81016	0.28133	4252.00000	2.880	0.003999	**
hemisphereleft:antpospost	-1.53043	0.25530	4252.00000	-5.995	2.21e-09	***
hemisphereright:antpospost	-1.61491	0.25530	4252.00000	-6.326	2.78e-10	***

The results of the model reveal a marginally significant effect of relatedness for the baseline levels, indicating that at the center of the scalp (i.e., electrode Cz) there is a marginally significant effect of Relatedness in the Identity condition. The positive direction of the coefficient for Relatedness indicates that the mean amplitude is more positive (i.e., the negativity associated with the N250 is attenuated. There is an interaction of Condition x Relatedness for the Semantic items only. This indicates that the effect of Relatedness found in the baseline Identity items is different in the Semantic items. The results of the model can be visualized in the topoplots in Figure 3.9 below where the mean amplitude of the Unrelated prime was subtracted from the mean amplitude of the Related prime. A follow-up model on Semantic items only revealed no effect of Relatedness (*p*>.49).

Figure 3.9. Topoplots (Related – Unrelated) 100 – 300 ms time-window, L1 French only



The results of the model on L1 French speakers in the early time-window show that in the early stages of lexical processing, the negativity found in the 100 – 300 ms time-window is attenuated (i.e., more positive) when the prime is either the same form as the target (Identity), morphologically related, or orthographically related. This priming effect is found not significantly stronger at any one topographical site on the scalp, and can be described as having a global distribution. These results are in line with the predictions that the N250 will be modulated by prime and target words overlapping in orthography, and this is independent of shared morphology between prime and target.

100 – 300 ms time-window analysis, L2 French

For the model on L2 French speakers only, proficiency (as measured by the LexTale-inspired task) was included as a continuous variable to test if any priming effects that may be found are modulated by proficiency. The model that best fit the data for the L2 French group in the 100 – 300 ms time-window included Condition, Relatedness, log-transformed LexTale, Hemisphere, and Anteriority, as well as interactions of Condition x Relatedness, Condition x log-transformed LexTale, Relatedness x log-transformed LexTale, log-transformed LexTale x Anteriority, Hemisphere x Anteriority, and Condition x Relatedness x log-transformed LexTale. Due to the size of the *lmer* model output, only the relevant results (i.e., those pertaining the Relatedness, Condition, or group) will be presented here. The complete *lmer* summary is provided in Appendix H.

The model revealed no significant simple effects of Relatedness or Condition, though there were significant interactions of Condition x Relatedness for the Morphological (t (4135) = -2.175, p<.03) and Semantic conditions (t (4135) = -4.077, p<.001), as well as a marginal interaction of Condition x Relatedness for the Orthographic condition (t (4135) = -1.698, p=.089). Additionally, there was a three-way interaction of Condition x Relatedness x LexTale for the Semantic condition (t (4135) = -2.618, p<.01). To further investigate the interactions of Condition x Relatedness, follow-up models were conducted for each condition separately.

The best model for the Identity condition included Relatedness, Hemisphere, and Anteriority as well as an interaction of Hemisphere x Anteriority as fixed effects. The results reveal a significant effect of Relatedness (t (1030) = 3.493, p<.01), indicating that related primes elicit significantly more positive amplitudes than unrelated primes (i.e., the negativity is attenuated). The model also showed a significant effect of Hemisphere for the left side (t (1030) = -2.047, p<.05), indicating overall more negative amplitudes on the left compared to the midline. There was also a significant effect of Anteriority for the anterior sites (t (1030) = 2.993, p<.01) and the posterior sites (t (1030) = -6.095, p<.001), indicated that compared to the central sites, the anterior sites were more positive overall, and the posterior sites were more negative overall.

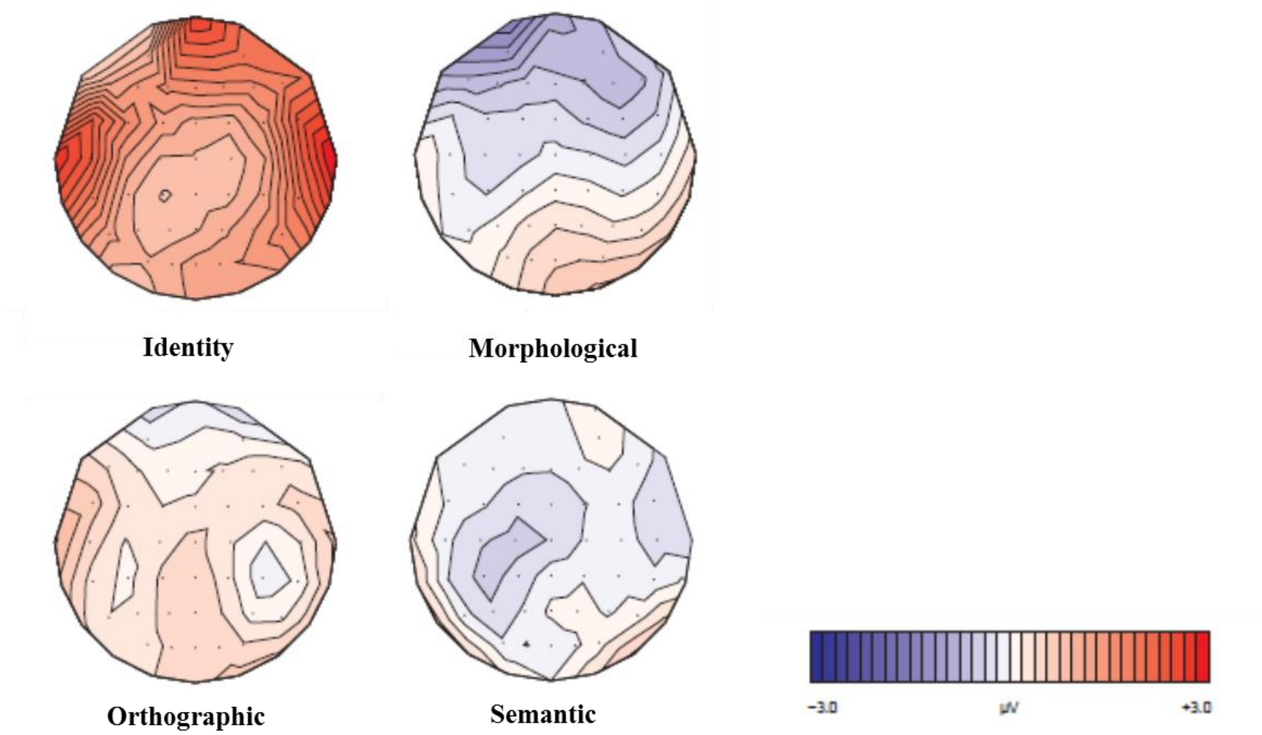
The best model for the Morphological condition included Relatedness, Hemisphere, and Anteriority, as well as interactions of Related x Anteriority and Hemisphere x Anteriority as fixed effects. The results of the model showed no effect of Relatedness (p>.5). There was a significant effect of Anteriority for the anterior sites (t (1029) = 3.022, p<.01) and for the posterior sites (t (1029) = -5.774, p<.001), indicating that compared to the central sites, anterior sites are overall more positive and posterior sites are overall more negative.

The best model for the Orthographic condition included Hemisphere, Anteriority, and the interaction of Hemisphere x Anteriority. There was a significant effect of Anteriority for the anterior sites (t (1032) = 3.196, p<.01) and for the posterior sites (t (1032) = -5.973, p<.001), indicating that compared to the central sites, anterior sites are overall more positive and posterior sites are overall more negative. Like the Morphological condition, there is no effect of Relatedness for Orthographic primes in this time-window.

The best model for the Semantic condition included Relatedness, log-transformed LexTale, Hemisphere, and Anteriority, as well as interactions of Relatedness x log-transformed LexTale, Relatedness x Anteriority, log-transformed LexTale x Anteriority, Hemisphere x Anteriority, and Relatedness x log-transformed LexTale x Anteriority as fixed effects. There was no effect of Relatedness ($p>.2$). There was a significant effect of Anteriority for the anterior sites (t (1023) = 3.487, $p<.01$) and for the posterior sites (t (1023) = -3.208, $p<.001$), indicating that compared to the central sites, anterior sites are overall more positive and posterior sites are overall more negative.

The results of the models can be visualized in the topoplots in Figure 3.10 (below). The topoplots show the difference between the related prime condition and the unrelated prime condition (related mean voltage minus unrelated mean voltage). The red colors indicate that the difference of conditions yields a positive difference (i.e., the related prime is more positive than the unrelated), whereas the blue colors indicate that the difference of condition yields a negative difference (i.e., the related prime is more negative than the unrelated prime). As can be seen in Figure 3.10, only in the Identity condition does the difference in Relatedness reveal a more positive mean voltage in the related prime items compared to the unrelated prime items. That is, only in the Identity condition does the related prime attenuate the N250 EEG component. The topoplot also shows that the difference between related and unrelated primes is greatest at the anterior midline and lateralized central electrode sites.

Figure 3.10. Topoplots (Related – Unrelated) 100 – 300 ms time-window, L2 French only



To summarize the findings in the early (100 - 300 ms) time-window for the L2 French group, the analyses reveal that only primes that are identical to the target offer significant priming effects. When the prime is the exact same form as the target the negativity in the 100 – 300 ms time-window is attenuated (i.e., less negative). No other condition offers any significant priming effect at this stage of lexical access in the non-native French speakers. These results are different from the native French speakers. For the native French speakers, the N250 component was modulated by shared orthography between prime and target. That is, for the native French speakers, the N250 was significantly attenuated by the Identity, Morphological, and Orthographic primes. The results of the N250 analyses for the non-native French speakers show only repetition priming effects in the early stages of lexical access. The results indicate different sensitivities at the early stages of lexical access in native and non-native French speakers.

Discussion *Experiment 2*

Experiment 2 aimed to investigate if morphological processing unfolds overtime in a qualitatively similar way for native and non-native French speakers. Like Experiment 1, Experiment 2 involved native and non-native French speakers completing a masked priming lexical decision task where the relationship between prime and target was either identical, morphological, orthographic, semantic, or unrelated. Experiment 2 differed from Experiment 1 by including EEG recording, which allows for investigation of lexical access moment-by-moment at the brain-level, independent of behavioral responses. EEG recording offers a number of key benefits when investigating the time-course of linguistic processing. Namely, EEG can capture (1) if a brain response is elicited by a given linguistic manipulation; (2) when specific linguistic features influence the EEG data; and (3) it can distinguish qualitatively different brain processes.

It was predicted that if French speakers (native and non-native) decompose morphologically complex words into stem and affix (as found in Experiment 1), the negativity in the N400 time-window would be significantly less negative (attenuated) when the prime and target shared morphology (i.e., in the identity and morphological conditions) compared to when the prime and target were unrelated. Additionally, it was predicted that the attenuation of the negativity from shared morphology would be greater than any attenuation from primes that overlap in orthography or semantics with the target. For the non-native French speakers, it was predicted that if lower level learners are unable to decompose inflected words, but higher level learners are able to do so, proficiency (as measured by the French LexTale task) should interact with the priming effect for the morphological condition.

The results from Experiment 2 reveal that both native and non-native French speakers show a significant attenuation of the negativity in the N400 time-window when the prime overlaps morphologically with the target (i.e., in the identity and morphological conditions). In both the native and the non-native French groups, this effect was found at posterior electrode sites. Importantly, the attenuation of the N400 when prime-target pairs shared morphology cannot be attributed to the fact that the morphologically related pairs also overlap in orthography and semantics. Neither the orthographic nor the semantic primes significantly attenuated the N400 at the posterior electrode sites. These results are consistent with lexical processing models that predict morphological processing and a morphological level of representation in the lexicon (e.g., Stockall & Marantz, 2006; Taft, 2004). The significant and equivalent priming effect for the N400 component in the identity and morphological prime conditions indicates that the shared morphology between the prime and target words is the cause of the attenuation of the negativity. Given the difference in priming effects in the orthographic and semantic prime conditions, the morphological priming effect cannot be explained by virtue of shared orthography and semantics between prime and targets in the identity and morphological conditions. Given that the results of this study are consistent with predictions from models of morphological processing that posit decomposition and access to a morphological level of representation, the results of Experiment 2 can be interpreted as evidence that inflected French verbs are decomposed into morphological constituents (e.g., *pensons*→*pens+ons*), and these are the units of representation in the lexicon that are activated when inflected forms are visually presented (similar to Royle et al., 2012). The results of Experiment 2 contribute to the on-going debate on the nature of lexical representations (i.e., morphological representation vs whole-word representation), though the results of the study are neutral to the additional debate on single-mechanism (e.g., Stockall & Marantz, 2006) versus dual-mechanism (e.g., Baayen et al., 1997; Marslen-Wilson et al., 1994) models of morphological processing, which the current study did not intend to adjudicate between.

Experiment 2 does provide further insight into how native-speakers process inflected words, but the main aim of the study was to shed new light on how people who learned a second language after childhood process inflected words. The current behavioral literature on non-native morphological processing has offered unclear results about whether learners are able to decompose morphologically complex words into morphological constituents and access a morphological level of representation in the lexicon. The results from Experiment 2 bring a new perspective to this on-going debate by investigating L2 morphological processing at the brain-level. The results from Experiment 2 suggest that, just like native French speakers, adult learners of French are able to decompose morphologically structured words, and the non-native lexicon contains a morphological level of representation. These findings are in direct opposition to claims made by Clahsen and colleagues who have argued that individuals who learn a second language after childhood are insensitive to the morphological structure of inflected words. In many of their studies, Clahsen and colleagues have argued that non-native speakers are insensitive to the morphological structure in inflected words such as *boiled*, and consequently are unable to decompose these types of words into morphological constituents. The consequence of this non-native-like processing routine is that the lexicon in the non-native language is claimed to contain unanalyzed whole-forms of complex words, which is qualitatively different from the structure of the native lexicon. The EEG and behavioral results in Experiment 2 indicate that non-native speakers do indeed demonstrate sensitivity to morphological structure of inflected forms, and the structure of the non-native lexicon is qualitatively similar to the structure of the native lexicon; both contain morphological units of representation.

An important finding in Experiment 2 is that the ability to decompose morphologically complex words was found across the proficiency range that was tested. The statistical analyses showed no interaction of French proficiency when testing the priming effects. This finding was unexpected but offers very interesting insight into what linguistic processes are available to even lower-level learners. Recall that Ullman predicts that with increased exposure and proficiency in the language, the availability of the procedural memory system in the non-native speakers will increase, and learners will begin to have access to the brain mechanisms responsible for decomposing regularly inflected forms. In other words, Ullman predicts that lower-level learners should not show evidence of morphological processing, but higher-level learners should qualitatively resemble native speakers in this capacity.

The results from Experiment 2, like the results in Experiment 1, are only partially in line with Ullman's predictions. The participants in Experiment 1 and Experiment 2 showed native-like processing of morphologically complex words, which Ullman predicted should be possible.

However, the results of Experiment 2 discord with the prediction that proficiency is the variable that allows learners to process inflection in a native-like way. As in Experiment 1, the participants in Experiment 2 constituted a wide-range of French proficiency (from low-level to high-level), yet the learners as a group are showing evidence of morphological priming, and proficiency does not modulate the priming effect. This unexpected finding indicates that proficiency in fact is not the variable that modulates access to brain mechanisms responsible for morphological decomposition. Instead, the results from Experiment 2 suggest that morphological decomposition may be a linguistic processing routine that is available to non-native speakers even at the early stages of learning.

Experiment 2 also aimed to investigate how lexical access unfolds over time in native and non-native speakers. The results for the N400 EEG component indicate similar morphological processing in native and non-native French speakers. However, this component only accounts for one time-window of investigation. The other time-window of interest (for the N250 component) captured earlier stages of lexical processing. The analyses of the N250 component revealed qualitative differences between native and non-native French speakers in terms of what kinds of linguistic information they are sensitive to at this point in time. In the native French speakers, the N250 component was influenced by shared orthography between prime and target words. The negativity was significantly and equally attenuated in the identity, morphological, and orthographic prime conditions, indicating that the component is influenced by shared orthography between prime and target words. In the non-native French speakers, however, the N250 was only affected by repetition priming (i.e., the identity condition). This finding indicates that at this stage of lexical access, non-native speakers are less sensitive to the orthographic form of words compared to native speakers.

The lack of sensitivity to orthographic overlap between prime and target at this stage of lexical access suggests interesting differences between native and non-native speakers, but it does not affect the finding of morphological processing suggested by the analyses of the N400 component. One notable consequence of this diminished sensitivity to orthographic overlap for the non-native speakers is that these results are contradictory to recent claims that non-native speakers may in fact be *more* influenced by orthography than native speakers are. In a recent study by Heyer & Clahsen (2014), native and non-native English speakers completed a masked priming lexical decision task where prime-target pairs were either related by derivational morphology (e.g., *scanner-scan*) or orthographic overlap (e.g., *scandal-scan*). Both native and non-native speakers showed priming effects for the derived items, but only the non-native speakers showed priming for orthographically related items. The authors argue that non-native speakers may be more influenced by surface-form properties of words (i.e., orthography) in the early stages of word recognition than native-speakers are. The analyses of the N250 component in Experiment 2 are in opposition to this claim. The non-native speakers in Experiment 2 instead showed *diminished* sensitivity to orthography in the early stages of lexical access compared to native speakers.

Overall, Experiment 2 shed new light on the investigation of lexical access in non-native speakers. Both native and non-native French speakers showed evidence of decomposing inflected verbs into stem and affix, and accessing a morphological level of representation in the lexicon. This ability was found across non-native speakers, independent of their French proficiency. There was, however, a difference of sensitivity to orthography in the earlier stage of lexical access. The native speakers showed sensitivity to shared orthography between prime and target for the N250 component, but non-native speakers only showed sensitivity to complete overlap (identity) between prime and target in this stage of lexical access.

Chapter 4: General Discussion

This dissertation aimed to investigate the nature of lexical representation and processing routes for inflected words in native and non-native French speakers. Both Experiment 1 and Experiment 2 demonstrate that native and non-native speakers can show evidence of decomposing inflected words into stem and affix, and that they activate a morphological unit in the lexicon. Additionally, both experiments also demonstrate that native-like processing of inflection is available at early stages of L2 learning. Previous studies investigating if native and non-native speakers process morphological structure in a qualitatively similar way have created an unclear picture about whether, and under what circumstances, adult learners of a second language are able to demonstrate sensitivity to morphological structure. This dissertation addressed many of the methodological issues that have contributed to the lack of consistency in L2 morphological processing studies. Specifically, both experiments included additional test conditions (orthographic and semantic) to allow morphological processing to be distinguished from orthographic or semantic processing. Without these conditions, the experiments would not be able to adjudicate between morphological and non-morphological models of lexical processing. Additionally, the data in both experiments were analyzed using techniques that allowed for much of the item and subject variability to be accounted for. For example, the analyses treated target frequency and L2 proficiency as continuous variables instead of artificially collapsing these variables into discrete groups (e.g., high- and low-level learners). Finally, Experiment 2 analyzed linguistic processing at the brain-level, which is the first time this has been done to investigate morphological decomposition in a non-native population. This technique has the advantage of looking at brain-level responses independent of behavioral responses.

The findings in Experiments 1 and 2 run counter to the proposal by Clahsen and colleagues that adult learners of a language lack sensitivity to inflectional morphology. Clahsen and colleagues posited that the diminished (or complete lack of) sensitivity to inflection in their studies is the result of a deficient representation of inflection in the L2 grammar, which is to say there is a fundamental difference between how native and non-native speakers process inflected words. According to Clahsen and colleagues, the lack of sensitivity to inflection is not predicted to change with increased proficiency or experience with the language. Again, the findings in Experiments 1 and 2 run counter to these claims. The studies presented in this dissertation demonstrate that native-like processing of inflectional morphology is available to L2 learners, even those at low levels of proficiency.

While the results regarding proficiency effects are not in line with predictions by Clahsen and colleagues, the findings are in line with one tenet of Ullman's model. He predicted that non-native speakers at early stages of L2 acquisition will be heavily reliant on the declarative memory system to store complex words, but with increased proficiency and exposure to the language, they should be able to proceduralize their grammatical knowledge of the L2, which will allow them to decompose inflected forms. The findings in the present dissertation are in line with Ullman's prediction that morphological decomposition is possible in a second language. Where the present findings diverge from Ullman's predictions is in the factor that allows a learner to gain access to the brain mechanisms responsible for decomposition. The two studies presented here do not support Ullman's prediction that proficiency is the factor that allows a learner to decompose inflected words because there was no evidence in the analyses that lower- and higher-level learners were processing morphology differently.

The two experiments in this dissertation aimed to test the claims put forth by both Clahsen and colleagues, and by Ullman. Experiment 1 used a masked priming lexical decision task to investigate if native English speakers who learned French as a second language after childhood are able to process verbal inflections in a qualitatively similar way as native speakers, and whether proficiency in French modulated this ability. It was predicted that if learners are able to decompose inflected forms into stem and affix, and access a morphological level of representation in the lexicon, the lexical decision times to stem-form target items would be significantly faster when a morphologically related prime word preceded the target compared to when an unrelated prime word preceded the target. Additionally, it was predicted that the priming effect from morphologically related primes would be significantly greater than any facilitation found when the prime was orthographically or semantically related to the target. That is, if the true nature of the facilitation in the morphological prime condition is the shared morphology and not the shared orthography or shared semantics, the priming effect from morphologically related primes should be distinct from any orthographic or semantic priming.

The results of Experiment 1 showed morphological priming for both native and non-native French speakers. In both groups, targets that were preceded by morphologically related primes (identity and morphological conditions) elicited equivalent and significantly faster reaction times than targets preceded by an unrelated prime. Additionally, for both language groups, neither the orthographic nor the semantic prime conditions offered significant priming effects compared to unrelated conditions. The results were in line with predictions that the inflected primes are decomposed into stem and affix, allowing the stem to activate a morphological unit in the lexicon, which in turn allowed for faster target recognition. These findings are not in line with predictions by Clahsen and colleagues who have argued that learners are less sensitive to inflection, and are unable to decompose inflected forms into stem and affix. These findings are, however, in line with predictions by Ullman in that learners are showing native-like sensitivity to inflection, and are demonstrating that they are able to decompose inflected forms into morphological constituents.

Experiment 1 also tested if the ability for learners to decompose inflected forms into stem and affix was modulated by proficiency. Analyses on the data from the non-native speakers alone demonstrated that proficiency (as measured by the cloze test and French LexTale test) does not affect the morphological priming effect. The participants in Experiment 1 varied greatly in their French proficiency (low-level to high-level), but the analyses show that the morphological priming effect was found across the proficiency range. This finding was not in line with Ullman's prediction about the role of proficiency in the availability of the mechanisms responsible for decomposition. Such a finding suggests that native-like sensitivity to inflection may be available to learners at much earlier stages of learning than previously predicted. Experiment 1 contributed to the literature on L2 morphological processing by demonstrating that adult learners of a language can demonstrate sensitivity to morphological structure, and can process complex words according to their morphological constituents. While the results of Experiment 1 are not in line with findings from previous masked priming lexical decision studies from Clahsen and colleagues, the findings are consistent with results from a series of previous studies that do suggest native-like processing of inflection.

As discussed in greater detail above (Chapter 2), Basnight-Brown et al. (2007) used a cross-modal priming task and found that L2 learners of English (L1 Mandarin or Serbian) are able to decompose regularly inflected English past tense forms into stem and affix, similar to native English speakers. Feldman et al. (2010) found similar results for Serbian learners of English in a masked priming task, as well. While both Basnight-Brown et al. (2007) and Feldman et al. (2010) argued that non-native speakers process inflected forms in a native-like way, neither study included an identity prime. The lack of an identity prime condition limited the studies' ability to argue that an inflected form is decomposed into stem and affix, leading to equal priming as would be expected when the prime was the exact same form as the target. Experiment 1 added further support to the claim that non-native speakers can show morphological facilitation in a priming study, but addressed the methodological issue that limited previous studies' ability to argue that non-native speakers are native-like in their ability to decompose inflected forms into morphological constituents. The results from Experiment 1 additionally complement the findings in Coughlin & Tremblay (2015), which used a masked priming word naming task to test if L2 French speakers are able to decompose inflected forms. The results from Coughlin & Tremblay found that learners of French are able to show evidence of morphological priming, but the priming effect was greater for more advanced learners. The results from Experiment 1 similarly show evidence of morphological priming, but do so using a task (masked priming lexical decision) that is generally considered to be a very powerful tool for investigating morphological processing in native and non-native speakers.

Experiment 2 investigated the time-course of morphological processing in native and non-native French speakers. Specifically, Experiment 2 aimed to investigate if the L1-L2 similarities in behavioral responses in Experiment 1 were accomplished in a qualitatively similar way at the brain-level. Experiment 2 used the same masked priming lexical decision task as was used in Experiment 1, but had participants complete the task while EEG data were recorded from their scalp. The addition of EEG data put Experiment 2 in a position to test if native and non-native French speakers show similar brain responses when processing inflected words. Experiment 2 offers unique insight into L2 processing as it is the first study (to my knowledge) to incorporate a masked priming lexical decision task with EEG recording to test non-native speakers of a language.

In line with previous studies on native speakers, it was predicted that morphologically related primes would influence the N400 EEG component. Specifically, when the prime word and the target word shared morphology (identity and morphological conditions), it was predicted that the N400 component would be attenuated (i.e., less negative) compared to the N400 when the prime and target are unrelated. Additionally, it was predicted that the attenuation of the N400 would be significantly greater when the prime and target shared morphology compared to when the prime and target shared orthography or semantics. The results for both the native and the non-native speakers were in line with these predictions. For both language groups, the N400 was significantly attenuated when prime and target overlapped in morphology compared to when the prime and target were unrelated, and this effect was distinct from the effect of prime and target sharing orthography or semantics. In both the native and non-native French groups this effect was most prominent at posterior electrode sites, which is consistent with previous findings (e.g., (Holcomb & Grainger, 2006; Morris et al., 2010).

The findings of N400 attenuation for morphological related word pairs suggest that both native and non-native speakers processed the inflected primes in a similar way, according to their morphological constituents. The inflected primes were decomposed into stem and affix, leaving the segmented stem available to prime the target word, similar to how a stem prime (identity condition) was available to prime the target word. When investigating if proficiency modulated this effect in the non-native speakers, the models demonstrated that proficiency (as measured by the French LexTale) did not modulate the attenuation corresponding to the morphological priming effect. This indicates that the morphological priming effect was found across the proficiency range tested in Experiment 2 (which ranged from low-level to high-level).

The N400 EEG component is sensitive to shared morphology between prime and target. The attenuation of the N400 component in both the native and non-native French group indicate that both groups are sensitive to the shared morphology between an inflected form and the stem form. These results are the first to demonstrate native-like processing of inflectional morphology at the brain-level in a priming task. Similar to Experiment 1, Experiment 2 showed that native-like processing of inflection is available even at lower levels of proficiency, which is not in line with some predictions made by Ullman (2005).

Experiment 2 also investigated the early stages of lexical processing by analyzing the N250 EEG component. In many previous studies the N250 has been shown to be sensitive to shared orthography between prime and target in a masked priming task (see Chapter 3 for discussion). Whereas the N400 captured similar sensitivities in the native and non-native French groups, the N250 analyses suggest different sensitivities in native and non-natives speakers in the earlier stages of lexical access. In the native French group, the N250 was attenuated when the prime and target overlapped in orthography (identity, morphological, and orthographic conditions). This was in line with the findings of many previous studies (e.g., Royle et al., 2012). This finding further supports the claim that the early stages of lexical access in the visual modality are driven by the orthographic form of the word. This was not, however, the finding in the non-native French group. In the non-native French speakers, the N250 was attenuated only in the identity prime condition, with no effect from the other prime conditions. Such a finding suggests that the early stages of lexical access in non-native speakers may be less sensitive to the orthographic form of a word. This finding is particularly interesting because recent research on L2 lexical processing has suggested that non-native speakers may be more sensitive to orthography in the earlier stages of lexical access compared to native speakers (e.g., Heyer & Clahsen, 2014). The results from the N250 analyses in Experiment 2 suggest that in fact the opposite may be true: the early stages of L2 lexical processing may be *less* sensitive to orthography compared to the early stages of L1 lexical processing.

When comparing the French learner groups' N250 results in this dissertation and the results in Heyer & Clahsen (2014), it is important to keep in mind the difference in methodologies, and what can be concluded from each study. Heyer & Clahsen used a masked priming lexical decision task and found that learners showed priming for orthographic overlap (e.g., *scandal-SCAN*), leading the authors to conclude an early influence of orthography in lexical access for learners that is stronger than any early influence of morphology. However, it is important to note that their measurement (reaction time) captures post-lexical processes in addition to early pre-lexical processes, whereas early pre-lexical processes can be distinguished from post-lexical processes in the N250 time-window of an EEG recording. Their conclusion of *early* influences of orthography may therefore be considered somewhat premature, though it is important to include their findings of orthographic influence when considering the L2 masked priming literature as a whole.

Situating the findings

This dissertation aimed to investigate L2 inflectional processing by designing tasks that addressed a number of limitations found in previous studies. The limitations of previous studies may have been contributing to a rather unclear understanding of how non-native speakers process inflectional morphology. Specifically, the two experiments in this dissertation made use of stimuli that were designed to be able to best adjudicate between claims regarding morphological versus non-morphological processing (for native and non-native speakers). The inflected primes in this study carried the *–ons* inflection, which creates a complex form of low surface-frequency when concatenated to a verb stem. The fact that the inflected forms were of extremely low frequency made it highly unlikely that French speakers (native or non-native) would store the whole-form in the lexicon by virtue of its frequency properties. This is important because it has been proposed by some researchers that inflected forms of high enough frequency may not be processed morphologically, but instead stored in whole-form (e.g., Alegre & Gordon, 1999). By ensuring that all inflected forms were of low surface frequency, the experiments presented above were in an ideal position to capture morphological processing in both native and non-native French speakers.

The use of the *–ons* inflection offers additional strengths to the study due to its perceptual properties. It has been proposed by some L2 researchers that the perceptual salience of morphemes influences success of learning in the L2. For example, Goldschneider & DeKeyser (2001) hypothesized that perceptually salient morphemes[14] are learned earlier and with greater success compared to less perceptually salient morphemes. The *–ons* inflection would be considered perceptually salient according to Goldschneider & DeKeyser because it comprises an entire syllable and when the verb appears in phrase-final position, it is phonologically prominent[15]. The perceptual salience of the inflection may have contributed to the non-native speakers acquiring the morpheme in a native-like way, allowing them to decompose complex words carrying this inflection. Though native French speakers very rarely produce this form in speech, learners are taught this form in the classroom, and will be highly familiar with it.

The two experiments above also addressed a limitation in previous studies regarding the non-native participant group. Many of the studies reviewed above have tested groups of advanced speakers of the language. Testing a homogeneous group does not allow for a study to investigate the influence of proficiency on morphological processing. The experiments in this dissertation included a wide range of proficiency levels in French and included proficiency in the statistical analyses as a continuous variable. By including a range of proficiency levels that were not

[14] Goldschneider and DeKeyser (2001) quantify perceptual salience based on syllabicity (whether the morpheme comprises an entire syllable), stress/phonological prominence, number of phonemes, and phoneme sonority.
[15] Phase-final syllables in French are marked by increased duration and a rise in fundamental frequency (F0) (e.g., Tremblay et al., 2012).

artificially collapsed into groups (e.g., high- vs low-level), Experiments 1 and 2 were in a position to test Ullman's predictions about a qualitative shift in a learner's towards native-like processing. It was critical to include this range of French proficiency to test the predictions made by Ullman and Clahsen and colleagues regarding the role of proficiency, and ultimately, the analyses here revealed native-like morphological processing across the proficiency range.

Related to incorporating proficiency as a continuous variable in the analyses, this dissertation made use of statistical techniques that allow for much of the item and subject variability to be accounted for. In typical ANVOA analyses, data points are collapsed into means before running analyses, which means that some sources of variability may be lost in the averaging process. By using linear mixed-effects models, many item and subject variables were accounted for in the analyses. For example, the analyses included target frequency for each item a participant responded to. Similarly, trial order was also included for each participant. Including these variables into the analyses was beneficial to investigating the morphological priming effect because it was revealed in the analyses that target frequency and trial number do indeed play a role in how quickly an individual was able to make their lexical decision, and these influenced lexical decision times independent of priming. In other words, the statistical analyses were better able to explain how prime relatedness influences reaction time while also controlling for other variables that were not under investigation.

Finally, the experiments in this dissertation address a limitation of some previous studies by including important test conditions aside from the morphological prime condition. This dissertation was able to compare stem priming to morphological priming by incorporating the identity prime condition, which allowed for distinguishing *full* priming from *partial* priming. Additionally, orthographic and semantic prime conditions were included in the stimuli. If these conditions were not included in the study, the morphological priming effect that was found would not provide strong evidence for morphological processing via decomposition. Recall that non-morphological models also predict faster lexical decisions to morphologically related prime-target pairs. What distinguishes morphological and non-morphological models is that non-morphological models posit that the lexical decision facilitation arises by virtue of shared orthography and semantics between prime and target, and morphological models posit that the facilitation arises by virtue of shared morphology. In order to adjudicate between these models, and argue for morphological processing, it is necessary to tease apart morphological priming from semantic and orthographic priming. By including these test conditions Experiment 1 and 2 were in the position of providing evidence of morphological facilitation that cannot be attributed to the shared orthography and shared semantics between morphologically related words.

It is important to consider how the findings of this dissertation contribute to the field of second language acquisition as a whole. This field of study aims to understand the ways in which native and non-native speakers may differ, and why differences exist. Bley-Vroman’s Fundamental Difference Hypothesis (e.g., Bley-Vroman, 1990) takes the position that languages learned in childhood are learned via a domain-specific mechanism, which allows for native competence, but this is not the case for people who learn a non-native language later in life. The rationale of his position is that, unlike young language learners, older language learners are highly variable in their ultimate attainment, and very rarely reach native-like levels of competence. Consequently, second language acquisition theories must aim to explain the nature of the discrepancy between early- versus late-learner outcomes. He hypothesizes that domain-specific mechanisms cease to be available after childhood, and domain-general learning mechanisms are used in late language learning. The Fundamental Difference Hypothesis claims that it is this difference in learning is what leads to non-native outcomes. In other words, language learned later in life cannot resemble native language.

Other L2 hypotheses take the position that native-like competence of a language learned later in life is in fact possible, and that positing differences in learning mechanisms is not necessary hypothesis to explain differences in native and non-native language outcomes. For example, the Full Transfer/Full Access model (e.g., Schwartz & Sprouse, 1996) posits that the initial state of L2 learning is the end state of L1 learning, and that L2 learners have access to Universal Grammar (UG), allowing for native-like competence to be possible (though not guaranteed). Such a model treats L2 language learning as initially being filtered through the L1 (e.g., L1 grammar is applied to L2 vocabulary), but the L2 grammar can be learned to a native-like level because UG remains available for language learning. Importantly, in order to restructure the L2 grammar to match that of the target language, sufficient data must be provided to override the initial-state grammar. This is described as happening in a piece-meal fashion where some components of the target grammar are learned earlier than other components. Such a model explains the highly variable outcome of L2 learners as being attributable to insufficient data provided to restructure an initial-state feature of the L2 grammar.

Though this dissertation did not aim to adjudicate between broad second language theories, such as those mentioned above, the results of the two experiments presented here can inform L2 theories. This dissertation has shown that it is possible for late learners of a language to be qualitatively similar to native speakers in their behavior in a task, and at the brain-level. While the results from this dissertation cannot speak to the origin of this native-like ability (e.g., full access to UG, initial-state grammar not being detrimental), this dissertation can speak to the hypothesis that non-native languages are fundamentally different as regards how language is organized in the brain. The two experiments presented here suggest that, at least in one domain of language that is known to be difficult for learners, native-like representations and processing mechanisms are indeed available.

Future Research

The findings from the two experiments in this dissertation were somewhat surprising in showing that native-like processing of inflection is possible across a wide range of proficiency levels. Support for this comes from the behavioral and neurophysiological data. This finding is surprising because in the L2 literature it is often the case that native-like processing is only found at very high levels of proficiency (e.g., Rossi et al., 2006). Given that there are many previous similar studies that have argued that native-like processing of inflection may never be possible, the finding in this dissertation that even lower-level learners are native-like in this capacity warrants further investigation.

The findings in this dissertation highlight a number of interesting future directions to further investigate why the L2 French learners in Experiments 1 and 2 were able to demonstrate native-like sensitivity independent of French proficiency. One potentially interesting path is to investigate if the L1-L2 pairing is a contributing factor in a learner’s ability to demonstrate native-like sensitivity to inflection. Clahsen and colleagues predicted that L1-L2 similarities will not influence the sensitivity to inflection in the L2, but the question of L1-L2 pairing effects has long been a question of interest in the L2 literature (e.g., Hopp, 2010; Schwartz, 1990), and thus warrants further testing in the context of morphological decomposition. The L2 participants in the two experiments presented here were all native English speakers, who presumably decompose inflected forms in their native language (as found in the many studies testing English discussed above). It may be the case that this ability to decompose in the native language is easily transferred to the second language, which would explain why proficiency is not a contributing factor in an individual's ability to decompose (i.e., they can all do it because they are all native speakers of English). The hypothesis that the ability to decompose in L2 French comes from L1 English can be tested by including a new group of participants: L2 French learners who are native speakers of a language that lacks verbal inflection (e.g., Mandarin learners of French). If it is the case that the participants in Experiments 1 and 2 began learning French with the ability to decompose (as transferred from English), it would be predicted that L2 French learners who do not have a mechanism to decompose inflection in the L1 may show a different pattern in French. It may be the case that the properties of the L1 force learners to process morphological structure in a non-native way, and this is something that cannot be overcome, or it may be the case that morphological processing is something that can be acquired in a second language. Such a study with a new group of French learners would offer insight into how the properties of a native language influence how a second language is processed, which is a question of great interest to the field of second language acquisition in general.

In addition to testing the influence of L1-L2 pairing, the findings of this dissertation also raise the question of how the language learning environment may influence how the L2 is represented and processed. One may hypothesize that the French learners in Experiments 1 and 2 showed native-like sensitivity to inflection independent of their French proficiency because of the way in which they learned French. All of the L2 French speakers in Experiments 1 and 2 learned French (at least in part) in a North American classroom context. It is probable that many, if not all, of the French learners were exposed explicitly to the inflectional paradigm of French verbs. For example, many participants may have gone through conjugation drills where they consciously concatenated a verb stem with a verbal inflection. Such explicit rule-learning may have influenced the way they represent and process inflectional morphology. Some recent neurolinguistic research has investigated how people process grammatical gender in an artificial language (BROCANTO2) when they were either taught by receiving explicit grammatical rules compared to implicit exposure to rules (Morgan-Short, Sanz, Steinhauer, & Ullman, 2010), though it is unclear from the Morgan-Short et al. study whether or how type of exposure modulates morphological processing at any level of proficiency.

One possible way to go about testing if the learning context influences sensitivity to inflectional morphology would be to create a training study similar to Morgan-Short et al. (2010) where one group of participants is explicitly exposed to French conjugation rules and another group is exposed to French inflection without explicitly given the conjugation paradigm. By training people (who have no previous exposure to French) in one of these two groups, and then having them complete the masked priming lexical decision task, the role of learning environment on the outcome of Experiments 1 and 2 could be further explored. Such a study would be of great interest to people who are interested in best teaching practices to arrive at native-like processing. If it is the case that explicit rule-learning is a key component to processing complex words according to their morphological structure, this would be valuable information for language instructors to know.

Finally, the results of this dissertation leave open the question of how broadly the ability to decompose in a second language extends to other L2 processing abilities. This dissertation has shown that late L2 learners can show evidence of processing morphological structure, but this opens up the question as to when they make use of this ability. An interesting future avenue of investigation would be to have French learners complete the masked priming lexical decision tasks, but also complete a number of other tasks that test their sensitivity to morphological structure in a sentential context. For example, learners could complete a self-paced reading task and an auditory listening task to measure an individual's sensitivity to morphological features during sentence processing. The priming effect from the lexical decision task and the sensitivity to morphological features can then be examined to investigate if it is the case that people who are able to decompose (in the priming task) show native-like sensitivity to inflection in sentential contexts. Such a study would build a bridge between the current morphological decomposition literature and the morphosyntactic literature that currently do not intersect as frequently as one might expect, given their mutual interests in understanding L2 morphological processing. Such a study would be highly valuable in contributing to our overall understanding of how learners process morphological structure, and how they are able to deploy this online during comprehension.

Conclusions

The two experiments in this dissertation have provided evidence in support of the claim that morphologically complex words (specifically, inflected words) are exhaustively decomposed into morphological constituents, leading to activation of morphological units in the lexicon. The two experiments in this dissertation additionally demonstrated that morphologically complex words are processed in a qualitatively similar way in a native language and a second language learned after childhood.

The findings of this dissertation should be considered within a broader view of the study of learning a second language after childhood. Many studies in the L2 literature aim to understand why it is so difficult to achieve native-like proficiency in a language that is learned later in life, and often focus on the ways in which learners do not resemble native speakers. Recent decades have seen numerous hypotheses put forward that posit that there are fundamental differences between a native language and a second language, and this difference is not something that can be overcome by increased practice, exposure, or fluency (e.g., Bley-Vroman, 1990; Clahsen & Felser, 2006). The experiments presented in this dissertation are exciting in that they reveal native-like processing is in fact possible, at least in this one specific domain. And of additional interest, the results demonstrate that native-like processing in this one domain may in fact be available at very early stages in learning for some groups of learners.

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Appendices

Appendix A: Language Background Questionnaire

Appendix B: Cloze Test

Appendix C: French LexTale

Appendix D: Real Word Stimuli, Experiments 1 and 2

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Appendix G: Experiment 2, *lmer* 100-300 ms time-window analyses with L1 and L2 French

Appendix H: Experiment 2, *lmer* 100-300 ms time-window analyses for L2 French

Appendix I: Experiment 2, *lmer* 300-500 ms time-window analyses for L1 and L2 French

Appendix J: Experiment 2, *lmer* 300-500 ms time-window analyses L2 French

Appendix A

Language Background Questionnaire

Participant #:	Age:	Sex: M F	Major:

Have you ever had (check all that apply):
- ☐ vision problems?
- ☐ hearing impairment?
- ☐ language disability?
- ☐ learning disability?

If yes to any, please explain (including any corrections) ______________________________

What university year are you? Year ___ of ☐ undergraduate ☐ graduate studies.

What is **your** native language?

English: American Australian British Canadian S. African
French: Acadian Belgian Cajun Canadian French Swiss
African (specify) ____________

What is your **mother's** native language?

English: American Australian British Canadian S. African
French: Acadian Belgian Cajun Canadian French Swiss
African (specify) ____________

What is your **father's** native language?

English: American Australian British Canadian S. African
French: Acadian Belgian Cajun Canadian French Swiss
African (specify) ____________

What language(s) were used in your house from **birth to 5 years of age**?

English: American Australian British Canadian S. African
French: Acadian Belgian Cajun Canadian French Swiss
African (specify) ____________

What language(s) were used in your house from **6 to 11 years of age**?

English: American Australian British Canadian S. African
French: Acadian Belgian Cajun Canadian French Swiss
African (specify) ____________
Other (specify) ______________________________

What language(s) were used in your house from **12 to 17 years of age**?

English: American Australian British Canadian S. African
French: Acadian Belgian Cajun Canadian French Swiss
African (specify) ____________
Other (specify) ______________________________

In what **country/countries** did you live…

…as a child?	…as a teenager?	…as an adult?

Excluding language classes, in what language were you taught (e.g., math, history, etc.) in…

… elementary school?	… middle school?	… high school?

Please list all languages you know **in order of dominance**.

1)	2)	3)	4)	5)

Please list your languages **in order of acquisition** (beginning with native language).

1)	2)	3)	4)	5)

Please estimate your **global proficiency** in all the languages you know (beginner, intermediate, advanced, near-native, native).

Language	English	French			
Proficiency					

Please give the **percentage of time** you currently **use** each language (your percentages should add to 100%).

Language	English	French			
Percent					

If a text were available in all your languages, what **percentage of the time** would you **choose to read it** in each language (assume the original language of the text was a language you do not know)?

Language	English	French			
Percent					

When speaking a language with someone who is equally fluent in all your languages, **what percent of the time** would you choose to **speak** each of your languages?

Language	English	French			
Percent					

If French is not your native language…

How many years of French instruction have you received? ________________________________

What French dialects did your instructors speak (circle all that apply)?

Acadian Belgian Cajun Canadian French Swiss
African (specify) ______________

Were a majority of your instructors native French speakers? ☐ Yes ☐ No

At what **age** did you begin…

… learning French at school?	… listening to French?	…interacting with native French speakers?

Please provide information about your **experiences in a French speaking environment**.

Country	Age during visit	Length of visit (in months)	Context (study abroad, vacation, etc.)

How would you estimate your **proficiency in French** (beginner, intermediate, advanced, near-native) for…

…reading?	… writing?	… listening?	…speaking?

Please describe the **circumstances** in which you **currently use French** (e.g., French class, with friends, listening to music, watching movies, etc.) and how often you do so (e.g., daily, frequently, sometimes, rarely).

Activity/circumstances	Frequency

In your perception of your own French, **how much of an accent** would you say you have on a scale from 1-10 (1 being nearly indistinguishable from native French speakers)?

____

Appendix B

Cloze Test from Tremblay (2011)

Le taux de CO 2 dans l'atmosphère augmente plus vite que prévu

La croissance économique mondiale ___(1)___ provoqué un accroissement de ___(2)___ teneur en dioxyde de ___(3)___ (CO 2) dans l'atmosphère beaucoup ___(4)___ rapidement que prévu, selon une étude ___(5)___ lundi dans les comptes rendus de l'Académie ___(6)___ des sciences des États-Unis. Cette étude ___(7)___ que la concentration des émissions ___(8)___ gaz carbonique dans l'atmosphère a ___(9)___ de 35% en 2006, entre le début ___ (10)___ années 1990 et les ___(11)___ 2000-2006, passant de 7 à 10 milliards de tonnes ___(12)___ an, alors que le protocole de Kyoto prévoyait ___(13)___ en 2012, ces émissions responsables ___(14)___ réchauffement climatique devaient ___(15)___ baissé de 5% par ___(16)___ à 1990. "Les améliorations dans l'intensité carbonique de l'économie ___(17)___ stagnent depuis 2000, après trente ___(18)___ de progrès, ce qui a provoqué cette ___(19)___ inattendue de la concentration de CO 2 ___(20)___ l'atmosphère", indique dans ___(21)___ communiqué le British Antarctic Survey, ___(22)___ a participé à cette étude. __(23)___ les chercheurs, les carburants polluants ___(24)___ responsables de 17% de cette augmentation, ___(25)___ que les 18 % restant sont ___(26)___ à un déclin de la capacité des "puits" naturels comme ___(27)___ forêts ou les océans ___(28)___ absorber le gaz carbonique. " ___(29)___ y a cinquante ans, pour chaque tonne de CO 2 émise, 600 kg ___(30)___ absorbés par les puits naturels. ___(31)___ 2006, seulement 550 kg par tonne ont été ___(32)___, et cette quantité continue à baisser", explique ___(33)___auteur principal de l'étude, Pep Canadell, du Global Carbon Project. "La baisse de l'effi cacité ___(34)___ puits mondiaux laisse ___(35)___ que la stabilisation de cette ___(36)___ sera encore plus ___(37)___ à obtenir que ce que l'on pensait jusqu'à ___(38)___", indique pour sa ___(39)___ le British Antarctic Survey. Ces ___(40)___ obligent à une révision à la hausse ___(41)___ prévisions du Groupe intergouvernemental d'experts ___(42)___ l'évolution du climat qui, dans son ___(43)___ de février, tablait sur l'augmentation de la température ___(44)___ de la terre de 1,8°C à 4°C ___(45)___ l'horizon 2100.

English Translation from Tremblay (2011)

The Level of CO 2 in the Atmosphere Increases More Rapidly than Forecasted

The world economic growth ___(1)___ created an increase in ___(2)___ level of ___(3)___ dioxide (CO 2) in the atmosphere much ___(4)___ rapidly than anticipated, according to a study ___(5)___ on Monday in the reports of the United States ___(6)___ Academy of Sciences. This study ___(7)___ that the amount of emissions ___(8)___ carbon dioxide in the atmosphere has ___(9)___ by 35% in 2006, between the beginning ___ (10)___ the 1990's and of ___(11)___ 2000-2006's, going from 7 to 10 billions of tons ___(12)___ year, whereas the Kyoto protocol had anticipated ___ (13)___ in 2012, the emissions responsible ___(14)___ global warming should ___(15)___ decreased by 5% as ___(16)___ to 1990. "The improvements in the intensity of carbon dioxide for the ___(17)___ economy have stagnated since 2000, after thirty ___(18)___ of progress, which has triggered this unexpected ___(19)___ in the amount of CO 2

___(20)___ the atmosphere" , indicates in ___ (21)___ press release the British Antarctic Survey, ___(22)___ participated in this study. __(23)___ to researchers, polluting carbon emissions ___(24)___ responsible for 17% of this increase, ___(25)___ the remaining 18% are ___(26)___ to a
decline in the capacity of natural "wells" such _ __(27)___ forests or oceans ___ (28)___ absorb carbon dioxide. "Fifty years ___(29)___ , for each ton of CO 2 released, 600 kg ___(30)___ absorbed by the natural wells. ___(31)___ 2006, 550 kg per ton were ___(32)___ , and this amount continues to decrease," explains ___ (33)___ main author of the study, Pep Canadell, of the Global Carbon Project. "The decrease in the efficiency ___(34)___ the world wells suggests ___(35)___ the stabilization of this ___(36)___ will be even more ___(37)___ to obtain than what we thought up until ___(38)___ ," indicates, on the other ___(39)___ , the British Antarctic Survey. These ___(40)___ force a revision at a higher level of ___(41)___ forecast of the Intergovernmental ___(42)___ Group on climate change which, in their February ___(43)___ , estimated an increase of the ___(44)___ earth temperature from 1,8°C to 4°C ___(45)___ the 2100 horizon.

Multiple choice options for version adapted from Tremblay (2011) for this dissertation

Correct answer marked with *

Blank #	Option 1	Option 2	Option 3	Option 4
1	est	a*	peut	qui
2	la*	concentration	du	sa
3	carbon	charbon	carbonique	carbone*
4	augmenté	très	de	plus*
5	apparue	émise	publiée*	scolaire
6	nationale*	américaine	première	scientifique
7	avertit	souligne*	montrait	trouvait
8	du	en	pour	de*
9	grossi	plus	baissé	augmenté*
10	les	des*	plusieurs	quelques
11	années*	ans	pendant	entre
12	par*	chaque	d'	un
13	cela	moins	qu'*	trouver
14	de	au	du*	le
15	avoir*	être	faire	que
16	année	contre	mois	rapport*

17	qui	mondiale*	sont	déjà
18	années	ans*	pourcent	mois
19	accroissement	amélioration	situation	croissance*
20	de	en	à	dans*
21	ce	le	un*	cette
22	qui*	il	on	que
23	chez	parmi	Selon*	tous
24	sont*	étaient	ont	seront
25	ainsi	bien	tandis*	ce
26	dus*	absorbés	responsables	grâce
27	des	les*	ces	de
28	pour	va	à*	qui
29	Elle	On	Il*	Là
30	sont	étaient*	ont	qui
31	Dans	Depuis	Pendant	En*
32	émis	absorbés*	augmentés	baissés
33	un	d’	l’*	par
34	de	des*	les	en
35	penser*	craindre	savoir	parce
36	capacité	concentration*	pollution	tendance
37	difficile	facile	efficace	qu’
38	avant	ici	là	present*
39	rapport	communiqué	part*	justification
40	résultats*	auteurs	études	événements
41	de	des*	les	avec
42	dans	dont	pour	sur*
43	compte	projet	rapport*	mois
44	atmosphère	chaude	mondiale	moyenne*
45	à*	dans	vers	en

Appendix C
French LexTale

Type	Item	Type	Item	Type	Item	Type	Item
Word	aboiement	Word	faiblement	Word	orme	Nonce	dérissement
Word	alloué	Word	fautif	Word	parleur	Nonce	dessection
Word	aquarelle	Word	féerique	Word	pauvreté	Nonce	écossien
Word	arborer	Word	feigner	Word	péninsule	Nonce	éguillation
Word	boiter	Word	fichu	Word	plénitude	Nonce	épalon
Word	carapace	Word	frêne	Word	plinthe	Nonce	fardeur
Word	casquer	Word	frisquet	Word	râper	Nonce	fécité
Word	cireux	Word	frôlement	Word	rechute	Nonce	goble
Word	congé	Word	fumet	Word	remerciement	Nonce	inviste
Word	contrecoeur	Word	grue	Word	ronfler	Nonce	jumeux
Word	contretemps	Word	hâtif	Word	rouleur	Nonce	louiller
Word	cote	Word	honnêteté	Word	rouvrir	Nonce	marcèlement
Word	couleuvre	Word	honteux	Word	sciemment	Nonce	mastille
Word	craintif	Word	houleux	Word	sournoisement	Nonce	méroce
Word	croître	Word	imbattable	Word	suraigu	Nonce	mouer
Word	croquis	Word	imbu	Word	surdoué	Nonce	mourd
Word	crûment	Word	impudique	Word	surnom	Nonce	noucher
Word	cuver	Word	indécision	Word	tireur	Nonce	orulaire
Word	décharge	Word	indigeste	Word	tympan	Nonce	ploit
Word	désuet	Word	indignité	Word	vaseux	Nonce	poscrition
Word	dormeur	Word	jetable	Nonce	algion	Nonce	pourdeau
Word	écume	Word	langui	Nonce	arateur	Nonce	rameux
Word	emballage	Word	lingot	Nonce	blanquer	Nonce	rinleur
Word	encadrement	Word	malaisé	Nonce	burlage	Nonce	sélion
Word	engrais	Word	minois	Nonce	clame	Nonce	spier
Word	entraîneur	Word	moqueur	Nonce	commisation	Nonce	surtiger
Word	envergure	Word	nuageux	Nonce	conradir	Nonce	tude
Word	épater	Word	ocre	Nonce	corcher	Nonce	tunèbre

Word	esclavage	Word	optique	Nonce	couprir	Nonce	valage
Word	étau	Word	ordurier	Nonce	darguer	Nonce	vuée

Appendix D
Real Word Stimuli Experiment 1 and 2

Condition	Related Prime	Unrelated Prime	Target
ID	tire	fuyons	TIRE
ID	rate	buvons	RATE
ID	fume	bubons	FUME
ID	dure	notons	DURE
ID	vide	laçons	VIDE
ID	mêle	parons	MÊLE
ID	pèse	gazons	PÈSE
ID	rêve	misons	RÊVE
ID	nage	gitons	NAGE
ID	tâche	ouvrons	TÂCHE
ID	doute	causons	DOUTE
ID	crève	privons	CRÈVE
ID	danse	prônons	DANSE
ID	tombe	enflons	TOMBE
ID	sonne	dansons	SONNE
ID	abuse	gâchons	ABUSE
ID	trace	dormons	TRACE
ID	parle	réglons	PARLE
ID	étale	cessons	ÉTALE
ID	reste	goûtons	RESTE
ID	manie	battons	MANIE
ID	vante	évadons	VANTE
ID	boucle	scellons	BOUCLE
ID	manque	semblons	MANQUE
ID	invite	pouffons	INVITE
ID	plonge	accédons	PLONGE
ID	répète	essayons	RÉPÈTE
ID	pulse	tardons	PULSE
ID	récite	évoquons	RÉCITE
ID	prépare	concluons	PRÉPARE
ID	borde	versons	BORDE
ID	observe	paniquons	OBSERVE
ID	ramasse	gravitons	RAMASSE
ID	explique	descendons	EXPLIQUE
ID	retourne	comprenons	RETOURNE
ID	moule	imitons	MOULE
Morph	osons	suons	OSE
Morph	tuons	ôtons	TUE
Morph	armons	lisons	ARME
Morph	citons	filons	CITE
Morph	errons	gênons	ERRE
Morph	jouons	potons	JOUE

Morph	louons	plions	LOUE
Morph	amusons	suivons	AMUSE
Morph	brisons	luttons	BRISE
Morph	cassons	voilons	CASSE
Morph	clouons	topions	CLOUE
Morph	entrons	jugeons	ENTRE
Morph	fondons	méfions	FONDE
Morph	gagnons	offrons	GAGNE
Morph	moquons	nommons	MOQUE
Morph	pensons	brûlons	PENSE
Morph	serrons	avouons	SERRE
Morph	signons	testons	SIGNE
Morph	valsons	cordons	VALSE
Morph	ajoutons	épousons	AJOUTE
Morph	blessons	échouons	BLESSE
Morph	bouffons	convions	BOUFFE
Morph	chassons	scrutons	CHASSE
Morph	prouvons	choppons	PROUVE
Morph	posons	fêtons	POSE
Morph	montrons	écrasons	MONTRE
Morph	pleurons	assurons	PLEURE
Morph	poussons	croulons	POUSSE
Morph	accusons	louchons	ACCUSE
Morph	soignons	couchons	SOIGNE
Morph	décidons	brillons	DÉCIDE
Morph	imposons	pelotons	IMPOSE
Morph	cherchons	bénissons	CHERCHE
Morph	échappons	résistons	ÉCHAPPE
Morph	frottons	daignons	FROTTE
Morph	exprimons	regagnons	EXPRIME
Orth	aidons	battons	AIME
Orth	durons	levons	DUPE
Orth	fixons	gelons	FIGE
Orth	gavons	visons	GARE
Orth	jurons	humons	JUGE
Orth	bavons	volons	BASE
Orth	ratons	fumons	RASE
Orth	votons	salons	VOLE
Orth	boudons	tissons	BOUGE
Orth	boutons	tondons	BOULE
Orth	brumons	collons	BRÛLE
Orth	coulons	donnons	COUPE
Orth	évidons	portons	ÉVITE
Orth	ferrons	glaçons	FERME
Orth	formons	ciblons	FORGE
Orth	lançons	chopons	LANGE

Orth	mandons	traçons	MANGE
Orth	mondons	cernons	MONTE
Orth	pannons	calmons	PANSE
Orth	parlons	adorons	PARIE
Orth	égarons	ballons	ÉGALE
Orth	planons	vendons	PLACE
Orth	routons	flânons	ROULE
Orth	sautons	mâchons	SAUVE
Orth	sonnons	frayons	SONGE
Orth	soupons	tâchons	SOUDE
Orth	bramons	surfons	BRASE
Orth	arrimons	cinglons	ARRIVE
Orth	arrosons	traquons	ARROGE
Orth	assumons	trottons	ASSURE
Orth	chantons	refusons	CHANGE
Orth	charmons	amassons	CHARGE
Orth	écoulons	désirons	ÉCOUTE
Orth	traînons	récitons	TRAITE
Orth	explosons	supplions	EXPLORE
Orth	commentons	encombrons	COMMENCE
Sem	aimons	vexons	ADORE
Sem	gobons	rayons	AVALE
Sem	créons	optons	FORME
Sem	crions	bayons	HURLE
Sem	attachons	butons	NOUE
Sem	valons	cirons	MÉRITE
Sem	agréons	campons	ACCEPTE
Sem	servons	lardons	DONNE
Sem	marions	voguons	ÉPOUSE
Sem	montons	pompons	GRIMPE
Sem	logeons	captons	HABITE
Sem	jetons	nouons	LANCE
Sem	narrons	prêtons	RACONTE
Sem	dénions	saluons	REFUSE
Sem	mettons	voulons	SITUE
Sem	lavons	topons	RINCE
Sem	remuons	barrons	TOURNE
Sem	vibrons	doutons	TREMBLE
Sem	bernons	frôlons	TROMPE
Sem	masquons	trompons	CACHE
Sem	frappons	existons	CLAQUE
Sem	adhérons	mouchons	COLLE
Sem	bronzons	glissons	DORE
Sem	inhibons	plaisons	EMPÊCHE
Sem	comptons	penchons	ESPÈRE
Sem	écrivons	invitons	NOTE

Sem	omettons	croquons	OUBLIE
Sem	croisons	résumons	PASSE
Sem	revêtons	abjurons	PORTE
Sem	laissons	effaçons	QUITTE
Sem	implorons	calculons	PRIE
Sem	caressons	apprenons	TOUCHE
Sem	dénichons	observons	TROUVE
Sem	assistons	discutons	AIDE
Sem	piquons	agitons	PERCE
Sem	choquons	tolérons	VEXE

Appendix E
Nonce word stimuli Experiment 1

Prime1	**Prime2**	**Target**	**Prime1**	**Prime2**	**Target**
rions	ayons	OYE	ôtons	irons	BRE
nions	fions	FRE	vidons	armons	ARCE
serons	tâtons	TÂFE	bâtons	topons	HOPE
aurons	tenons	TELE	soyons	vivons	VIME
irions	payons	VAYE	devons	volons	VOPE
bayons	tapons	LAPE	dînons	ramons	BAME
cédons	vêtons	LÊTE	disons	matons	JATE
lésons	lisons	LIME	humons	fêtons	FÂTE
semons	mêlons	MÊGE	basons	misons	RISE
prions	menons	NENE	gelons	optons	IPTE
buvons	noyons	NOVE	aérons	visons	VIGE
bavons	allons	OLLE	fixons	faxons	TOXE
cirons	vouons	POUE	notons	culons	GULE
épions	voyons	POYE	savons	gavons	HEVE
criions	guidons	FUIDE	hâtons	canons	LONE
tuerons	faisons	GAISE	tétons	étions	ÉGIE
aillons	gardons	GARGE	avions	virons	VORE
créions	sortons	GORTE	bottons	dictons	BOCTE
rayions	coupons	GOUPE	dormons	évitons	OVITE
bâclons	urinons	GRINE	fonçons	cachons	PACHE
oignons	barrons	HARRE	méfions	situons	PITUE
disions	pouvons	ROUVE	voulons	partons	HARTE
devions	tardons	SARDE	nageons	passons	HASSE
garions	tentons	TINTE	sentons	rendons	LENDE
venions	voguons	TOGUE	croyons	perdons	LERDE
caltons	brisons	TRISE	voilons	restons	LESTE
terrons	longeons	BONGE	écopons	tombons	MOMBE
pouvons	aboyons	IBOYE	éditons	gâchons	NÂCHE
rompons	roulons	FOULE	vaquons	sonnons	NONNE
plantons	côtoyons	PÔLOYE	forçons	foulons	DOULE
trottons	écoutons	ACOUTE	campons	élevons	ÉLEPE
renouons	avançons	AFANCE	collons	bottons	VOTTE
retenons	ignorons	AGNORE	coulons	vendons	VONDE
ennuyons	admirons	AMMIRE	traitons	forgeons	FIRGE
entêtons	attirons	ASTIRE	creusons	mangeons	GANGE
opposons	haussons	BAUSSE	adoptons	étonnons	ITONNE
épuisons	veillons	BEILLE	récitons	toussons	JOUSSE
espérons	joignons	BOIGNE	haïssons	baignons	LAIGNE
bloquons	trouvons	BROUVE	retirons	manquons	LANQUE
revenons	dévalons	DOVALE	secouons	marchons	LARCHE
libérons	occupons	ECCUPE	pouffons	végétons	LÉGÉTE

tournons	entamons	ENTEME	écartons	éclatons	ACLATE
envoyons	vengeons	PANGE	disposons	dégustons	DOFUSTE
respirons	ramassons	LEMASSE	pénétrons	repartons	LEPARTE
méprisons	demandons	RAMANDE	insistons	dépendons	DALENDE
cheminons	déplaçons	DOPLACE	démarrons	soulevons	PAULEVE
souhaitons	comprenons	POMPRENE	éclairons	composons	DIMPOSE
descendons	atteignons	ASTEIGNE	installons	traversons	TRALERSE
topons	filons	POVE	baisons	mentons	HENTE
gazons	plions	BAGE	plaçons	soupons	BROYE
menons	rêvons	RÊME	prenons	courons	IMIPE
boxons	talons	TABE	reculons	louchons	PLAUDE
tirons	jurons	JUTE	devenons	tutoyons	PLOQUE
citons	venons	VESE	excusons	rangeons	BACORD
pesons	tuions	TOUE	rentrons	exigeons	MADISE
tairons	imitons	BENTE	devinons	habitons	NARQUE
bradons	agitons	VERLE	risquons	trichons	PABITE
diluons	taisons	VERME	asseyons	échouons	OLINGE
valsons	versons	VIELE	estimons	imposons	ANNORE
voilons	fermons	HOUPE	étendons	aspirons	EGRATE
cognons	violons	HOURE	accédons	ébattons	VECEVE
égarons	nageons	COILE	arrivons	appelons	LATERE
sillons	bastons	ÉMOPE	méritons	pressons	GODONE
pigeons	avivons	ÉPITE	invitons	déposons	LAMELE
privons	blâmons	EXOGE	accusons	recevons	LOSARE
lions	ruons	FANGE	avons	oyons	VAE
touchons	hésitons	PEVINE	déployons	replaçons	COMPISE
médisons	heurtons	PISQUE	tabassons	remontons	AMPÊCHE
plaidons	marquons	PROTTE	rasseyons	répondons	COMCAGE
avortons	avalons	CHANCON	exagérons	naviguons	POUSTRE
mijotons	promenons	PROGRAN	exerçons	emportons	ATTRONTE
concevons	survivons	BEPONSE	arrosons	obstinons	ENDISAGE

Appendix F
Nonce word stimuli Experiment 2

Prime1	Prime2	Target	Prime1	Prime2	Target
rions	épions	ÈBE	ôtons	gelons	GÜE
nions	fions	FRE	vidons	armons	ARCE
serons	tâtons	TÂFE	bâtons	topons	HOPE
virons	soyons	SIGE	tenons	vivons	VIME
irions	payons	VAYE	veillons	volons	VOPE
bayons	tapons	LAPE	dînons	ramons	BAME
cédons	vêtons	LÊTE	optons	matons	JATE
lésons	talons	JÂLE	humons	fêtons	FÂTE
semons	mêlons	MÊGE	basons	misons	RISE
prions	menons	NENE	disons	gazons	GADE
buvons	noyons	NOVE	aérons	visons	VIGE
bavons	allons	OLLE	fixons	faxons	TOXE
cirons	vouons	POUE	notons	culons	GULE
irons	voyons	POYE	gâchons	habitons	HEVE
criions	guidons	FUIDE	tentons	lisons	LONE
tuerons	faisons	GAISE	tétons	étions	ÉGIE
aillons	gardons	GARGE	avions	aurons	AUPE
créions	sortons	GORTE	bottons	dictons	BOCTE
rayions	dormons	DOLME	coupons	évitons	OVITE
bâclons	urinons	GRINE	fonçons	cachons	PACHE
oignons	barrons	HARRE	méfions	situons	PITUE
disions	pouvons	ROUVE	voulons	partons	HARTE
devions	tardons	SARDE	nageons	passons	HASSE
garions	hâtons	HOBRE	sentons	rendons	LENDE
venions	tairons	TURRE	croyons	perdons	LERDE
caltons	brisons	TRISE	voilons	haïssons	HAUVE
terrons	longeons	BONGE	écopons	tombons	MOMBE
pouvons	aboyons	IBOYE	éditons	savons	SAUDE
rompons	mentons	MOUPE	vaquons	restons	RIQUE
plantons	cheminons	CHIRDE	forçons	foulons	DOULE
trottons	sonnons	SORADE	campons	élevons	ÉLEPE
renouons	avançons	AFANCE	collons	plaçons	PATUE
retenons	ignorons	AGNORE	coulons	vendons	VONDE
ennuyons	admirons	AMMIRE	traitons	forgeons	FIRGE
entêtons	attirons	ASTIRE	creusons	jurons	JOUVE
opposons	haussons	BAUSSE	adoptons	prenons	PRAULE
épuisons	devons	DÉFICE	récitons	toussons	JOUSSE
espérons	joignons	BOIGNE	écoutons	baignons	LAIGNE
bloquons	trouvons	BROUVE	retirons	manquons	LANQUE
revenons	dévalons	DOVALE	secouons	marchons	LARCHE
libérons	occupons	ECCUPE	pouffons	fourrons	FLOSSE
tournons	entamons	ENTEME	écartons	soupons	JOUPRE
envoyons	vengeons	PANGE	disposons	dégustons	DOFUSTE
respirons	ramassons	LEMASSE	pénétrons	repartons	LEPARTE

méprisons	demandons	RAMANDE	insistons	dépendons	DALENDE
côtoyons	déplaçons	DOPLACE	démarrons	soulevons	PAULEVE
souhaitons	comprenons	POMPRENE	éclairons	composons	DIMPOSE
descendons	atteignons	ASTEIGNE	installons	traversons	TRALERSE
topons	filons	POVE	touchons	hésitons	PEVINE
ayons	plions	BAGE	lions	ruons	FANGE
menons	rêvons	RÊME	avons	oyons	AIN
boxons	canons	TABE	baisons	roulons	HENTE
tirons	mangeons	TUDE	bottons	éclatons	ÉTIME
citons	venons	VESE	étonnons	courons	IMIPE
pesons	tuions	PIVE	reculons	louchons	PLAUDE
voguons	imitons	BENTE	devenons	tutoyons	PLOQUE
bradons	agitons	VERLE	excusons	rangeons	DRANCE
diluons	taisons	VERME	rentrons	exigeons	MADISE
valsons	versons	VIELE	devinons	gavons	AVERLE
voilons	fermons	HOUPE	risquons	trichons	PABITE
cognons	violons	HOURE	asseyons	échouons	OLINGE
égarons	nageons	COILE	estimons	imposons	ANNORE
sillons	bastons	ÉMOPE	étendons	aspirons	EGRATE
pigeons	avivons	ÉPADE	accédons	ébattons	VECEVE
privons	blâmons	EXOGE	arrivons	appelons	LATERE
médisons	heurtons	PISQUE	méritons	pressons	GODONE
plaidons	marquons	PROTTE	invitons	déposons	STOIVE
avortons	avalons	DOUINGE	accusons	recevons	LOSARE
mijotons	survivons	PROGE	rasseyons	répondons	COMCAGE
concevons	promenons	BEPONSE	exagérons	naviguons	POUSTRE
déployons	replaçons	COMPISE	exerçons	emportons	ATTRONTE
tabassons	remontons	MALECTE	arrosons	obstinons	PLERNE

Appendix G

lmer models from Experiment 2

Complete *lmer* summary for 100 -300 ms time-window analyses with L1 and L2 French together

```
Number of obs: 8480, groups:  subj, 53

Fixed effects:
                                  Estimate Std. Error         df t value Pr(>|t|)    
(Intercept)                        1.54327    0.38887   80.00000   3.969 0.000157 ***
Conditionmorph                    -0.24833    0.15128 8348.00000  -1.641 0.100733    
Conditionorth                     -0.22576    0.15128 8348.00000  -1.492 0.135656    
Conditionsem                       0.11091    0.15128 8348.00000   0.733 0.463507    
Relatedrel                         0.60740    0.28238  125.00000   2.151 0.033404 *  
langL2                             0.39344    0.53345   68.00000   0.738 0.463336    
hemisphereleft                     0.17008    0.18069 8348.00000   0.941 0.346574    
hemisphereright                   -0.31655    0.18069 8348.00000  -1.752 0.079828 .  
antposant                          1.58851    0.18432 8348.00000   8.618  < 2e-16 ***
antpospost                        -2.50318    0.16258 8348.00000 -15.396  < 2e-16 ***
Conditionmorph:Relatedrel         -0.03028    0.21394 8348.00000  -0.142 0.887458    
Conditionorth:Relatedrel          -0.33615    0.21394 8348.00000  -1.571 0.116178    
Conditionsem:Relatedrel           -0.98495    0.21394 8348.00000  -4.604 4.21e-06 ***
Conditionmorph:langL2              0.65567    0.21599 8348.00000   3.036 0.002408 ** 
Conditionorth:langL2               0.06181    0.21599 8348.00000   0.286 0.774773    
Conditionsem:langL2               -0.27891    0.21599 8348.00000  -1.291 0.196639    
Relatedrel:langL2                  0.66933    0.37254   91.00000   1.797 0.075701 .  
Relatedrel:hemisphereleft         -0.31502    0.14785 8348.00000  -2.131 0.033151 *  
Relatedrel:hemisphereright         0.03061    0.14785 8348.00000   0.207 0.835965    
langL2:hemisphereleft             -0.45887    0.14871 8348.00000  -3.086 0.002038 ** 
langL2:hemisphereright            -0.05835    0.14871 8348.00000  -0.392 0.694814    
langL2:antposant                  -0.26685    0.14161 8348.00000  -1.884 0.059551 .  
langL2:antpospost                  0.45722    0.13784 8348.00000   3.317 0.000913 ***
hemisphereleft:antposant           0.35307    0.20320 8348.00000   1.738 0.082331 .  
hemisphereright:antposant          0.76362    0.20320 8348.00000   3.758 0.000173 ***
hemisphereleft:antpospost         -1.36523    0.18441 8348.00000  -7.403 1.46e-13 ***
hemisphereright:antpospost        -1.24069    0.18441 8348.00000  -6.728 1.83e-11 ***
Conditionmorph:Relatedrel:langL2  -1.33323    0.30546 8348.00000  -4.365 1.29e-05 ***
Conditionorth:Relatedrel:langL2   -0.59841    0.30546 8348.00000  -1.959 0.050139 .  
Conditionsem:Relatedrel:langL2    -0.29281    0.30546 8348.00000  -0.959 0.337795    
```

Appendix H

lmer models from Experiment 2

Complete *lmer* summary for 100 -300 ms time-window analyses for L2 French

```
Number of obs: 4160, groups:  Subject, 26

Fixed effects:
                                       Estimate Std. Error         df t value Pr(>|t|)    
(Intercept)                             3.07914    1.36425   31.00000   2.257  0.03129 *  
Conditionmorph                         -1.11511    0.58115 4086.00000  -1.919  0.05508 .  
Conditionorth                          -0.86432    0.58115 4086.00000  -1.487  0.13702    
Conditionsem                            0.07702    0.58115 4086.00000   0.133  0.89457    
Relatedrel                              1.34942    0.98577   44.00000   1.369  0.17800    
log_lextale                             2.00766    2.68187   30.00000   0.749  0.45995    
hemisphereleft                         -0.56107    0.21286 4086.00000  -2.636  0.00842 ** 
hemisphereright                        -0.51455    0.21286 4086.00000  -2.417  0.01568 *  
antposant                               2.25393    0.44136 4086.00000   5.107 3.43e-07 ***
antpospost                             -2.48847    0.41557 4086.00000  -5.988 2.31e-09 ***
Conditionmorph:Relatedrel              -1.78729    0.82187 4086.00000  -2.175  0.02971 *  
Conditionorth:Relatedrel               -1.39534    0.82187 4086.00000  -1.698  0.08963 .  
Conditionsem:Relatedrel                -3.35075    0.82187 4086.00000  -4.077 4.65e-05 ***
Conditionmorph:log_lextale             -3.12639    1.14992 4086.00000  -2.719  0.00658 ** 
Conditionorth:log_lextale              -1.43822    1.14992 4086.00000  -1.251  0.21111    
Conditionsem:log_lextale                0.50316    1.14992 4086.00000   0.438  0.66173    
Relatedrel:log_lextale                  0.38288    1.95054   44.00000   0.196  0.84529    
log_lextale:antposant                   1.91025    0.75280 4086.00000   2.538  0.01120 *  
log_lextale:antpospost                 -0.46348    0.73293 4086.00000  -0.632  0.52719    
hemisphereleft:antposant                0.41462    0.29254 4086.00000   1.417  0.15648    
hemisphereright:antposant               0.71530    0.29254 4086.00000   2.445  0.01452 *  
hemisphereleft:antpospost              -1.19368    0.26548 4086.00000  -4.496 7.11e-06 ***
hemisphereright:antpospost             -0.85208    0.26548 4086.00000  -3.210  0.00134 ** 
Conditionmorph:Relatedrel:log_lextale  -0.87024    1.62623 4086.00000  -0.535  0.59259    
Conditionorth:Relatedrel:log_lextale   -0.94623    1.62623 4086.00000  -0.582  0.56070    
Conditionsem:Relatedrel:log_lextale    -4.25696    1.62623 4086.00000  -2.618  0.00889 ** 
```

Appendix I

lmer models from Experiment 2

Complete *lmer* summary for 300 -500 ms time-window analyses for L1 and L2 French

```
Number of obs: 8480, groups:  subj, 53

Fixed effects:
                                      Estimate Std. Error         df t value Pr(>|t|)
(Intercept)                            2.33885    0.51153   85.00000   4.572 1.63e-05
Conditionmorph                        -0.24079    0.28271 8336.00000  -0.852 0.394400
Conditionorth                         -0.61424    0.28271 8336.00000  -2.173 0.029830
Conditionsem                          -0.34687    0.28271 8336.00000  -1.227 0.219871
Relatedrel                             0.76605    0.33539  387.00000   2.284 0.022911
langL2                                -1.93217    0.68250   65.00000  -2.831 0.006173
hemisphereleft                        -0.02824    0.19377 8336.00000  -0.146 0.884131
hemisphereright                        0.55316    0.19377 8336.00000   2.855 0.004318
antposant                             -0.41143    0.30861 8336.00000  -1.333 0.182507
antpospost                             0.50618    0.28689 8336.00000   1.764 0.077705
Conditionmorph:Relatedrel              0.09633    0.39981 8336.00000   0.241 0.809607
Conditionorth:Relatedrel              -0.32589    0.39981 8336.00000  -0.815 0.415029
Conditionsem:Relatedrel               -0.58099    0.39981 8336.00000  -1.453 0.146214
Conditionmorph:langL2                  0.72538    0.25385 8336.00000   2.858 0.004280
Conditionorth:langL2                   0.46795    0.25385 8336.00000   1.843 0.065302
Conditionsem:langL2                    0.24502    0.25385 8336.00000   0.965 0.334456
Relatedrel:langL2                      0.24896    0.36169  128.00000   0.688 0.492489
langL2:hemisphereleft                 -0.28709    0.17478 8336.00000  -1.643 0.100502
langL2:hemisphereright                 0.51494    0.17478 8336.00000   2.946 0.003225
Conditionmorph:antposant               0.12893    0.33231 8336.00000   0.388 0.698039
Conditionorth:antposant                0.27970    0.33231 8336.00000   0.842 0.399987
Conditionsem:antposant                 0.02948    0.33231 8336.00000   0.089 0.929321
Conditionmorph:antpospost             -0.07145    0.32354 8336.00000  -0.221 0.825211
Conditionorth:antpospost               0.25207    0.32354 8336.00000   0.779 0.435945
Conditionsem:antpospost                0.05310    0.32354 8336.00000   0.164 0.869638
Relatedrel:antposant                  -0.83869    0.33231 8336.00000  -2.524 0.011626
Relatedrel:antpospost                  0.45493    0.32354 8336.00000   1.406 0.159732
langL2:antposant                       0.07246    0.16643 8336.00000   0.435 0.663316
langL2:antpospost                      0.85385    0.16199 8336.00000   5.271 1.39e-07
hemisphereleft:antposant              -0.80776    0.23882 8336.00000  -3.382 0.000722
hemisphereright:antposant             -0.17389    0.23882 8336.00000  -0.728 0.466556
hemisphereleft:antpospost             -1.20863    0.21673 8336.00000  -5.577 2.53e-08
hemisphereright:antpospost            -1.71544    0.21673 8336.00000  -7.915 2.66e-15
Conditionmorph:Relatedrel:langL2      -0.88344    0.35900 8336.00000  -2.461 0.013881
Conditionorth:Relatedrel:langL2        0.16889    0.35900 8336.00000   0.470 0.638054
Conditionsem:Relatedrel:langL2        -0.15017    0.35900 8336.00000  -0.418 0.675738
Conditionmorph:Relatedrel:antposant    0.16134    0.46995 8336.00000   0.343 0.731371
Conditionorth:Relatedrel:antposant     0.18467    0.46995 8336.00000   0.393 0.694364
Conditionsem:Relatedrel:antposant      0.80409    0.46995 8336.00000   1.711 0.087117
Conditionmorph:Relatedrel:antpospost   0.02574    0.45755 8336.00000   0.056 0.955143
Conditionorth:Relatedrel:antpospost   -0.46848    0.45755 8336.00000  -1.024 0.305923
Conditionsem:Relatedrel:antpospost    -0.50628    0.45755 8336.00000  -1.106 0.268543

(Intercept)                          ***
Conditionmorph
Conditionorth                        *
Conditionsem
Relatedrel                           *
```

```
langL2                                **
hemisphereleft
hemisphereright                       **
antposant
antpospost                            .
Conditionmorph:Relatedrel
Conditionorth:Relatedrel
Conditionsem:Relatedrel
Conditionmorph:langL2                 **
Conditionorth:langL2                  .
Conditionsem:langL2
Relatedrel:langL2
langL2:hemisphereleft
langL2:hemisphereright                **
Conditionmorph:antposant
Conditionorth:antposant
Conditionsem:antposant
Conditionmorph:antpospost
Conditionorth:antpospost
Conditionsem:antpospost
Relatedrel:antposant                  *
Relatedrel:antpospost
langL2:antposant
langL2:antpospost                     ***
hemisphereleft:antposant              ***
hemisphereright:antposant
hemisphereleft:antpospost             ***
hemisphereright:antpospost            ***
Conditionmorph:Relatedrel:langL2      *
Conditionorth:Relatedrel:langL2
Conditionsem:Relatedrel:langL2
Conditionmorph:Relatedrel:antposant
Conditionorth:Relatedrel:antposant
Conditionsem:Relatedrel:antposant     .
Conditionmorph:Relatedrel:antpospost
Conditionorth:Relatedrel:antpospost
Conditionsem:Relatedrel:antpospost
```

Appendix J

lmer models from Experiment 2

Complete *lmer* summary for 300 -500 ms time-window analyses L2 French

```
Number of obs: 4160, groups:  Subject, 26

Fixed effects:
                             Estimate Std. Error        df t value Pr(>|t|)    
(Intercept)                    3.6432     1.6776   32.0000   2.172  0.03748 *  
Conditionmorph                -0.6431     0.5449 4079.0000  -1.180  0.23802    
Conditionorth                 -1.2137     0.5449 4079.0000  -2.227  0.02599 *  
Conditionsem                  -0.5208     0.5449 4079.0000  -0.956  0.33925    
Relatedrel                     0.8863     0.3009  121.0000   2.946  0.00387 ** 
log_lextale                    6.7060     3.2740   30.0000   2.048  0.04937 *  
hemisphereleft                 0.3100     0.5150 4079.0000   0.602  0.54723    
hemisphereright                0.6509     0.5150 4079.0000   1.264  0.20631    
antposant                     -0.1598     0.5688 4079.0000  -0.281  0.77875    
antpospost                    -0.3986     0.5387 4079.0000  -0.740  0.45945    
Conditionmorph:Relatedrel     -0.7203     0.2571 4079.0000  -2.802  0.00510 ** 
Conditionorth:Relatedrel      -0.2798     0.2571 4079.0000  -1.088  0.27650    
Conditionsem:Relatedrel       -0.6522     0.2571 4079.0000  -2.537  0.01121 *  
Conditionmorph:log_lextale    -2.2176     0.9508 4079.0000  -2.332  0.01972 *  
Conditionorth:log_lextale     -2.4183     0.9508 4079.0000  -2.544  0.01101 *  
Conditionsem:log_lextale      -0.9118     0.9508 4079.0000  -0.959  0.33761    
log_lextale:hemisphereleft     1.1143     0.9258 4079.0000   1.204  0.22878    
log_lextale:hemisphereright   -1.0393     0.9258 4079.0000  -1.123  0.26167    
Conditionmorph:antposant       0.3198     0.3366 4079.0000   0.950  0.34205    
Conditionorth:antposant        0.4649     0.3366 4079.0000   1.381  0.16726    
Conditionsem:antposant         0.2772     0.3366 4079.0000   0.824  0.41018    
Conditionmorph:antpospost     -0.1190     0.3277 4079.0000  -0.363  0.71643    
Conditionorth:antpospost      -0.1856     0.3277 4079.0000  -0.567  0.57108    
Conditionsem:antpospost       -0.2262     0.3277 4079.0000  -0.690  0.48994    
Relatedrel:antposant          -0.4144     0.2380 4079.0000  -1.741  0.08174 .  
Relatedrel:antpospost          0.4053     0.2317 4079.0000   1.749  0.08031 .  
log_lextale:antposant          0.5301     0.8816 4079.0000   0.601  0.54770    
log_lextale:antpospost        -3.9437     0.8580 4079.0000  -4.596 4.43e-06 ***
hemisphereleft:antposant      -0.8856     0.3421 4079.0000  -2.589  0.00966 ** 
hemisphereright:antposant     -0.4468     0.3421 4079.0000  -1.306  0.19157    
hemisphereleft:antpospost     -1.3782     0.3104 4079.0000  -4.440 9.24e-06 ***
hemisphereright:antpospost    -1.7065     0.3104 4079.0000  -5.497 4.09e-08 ** 
```